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COMPARATIVE ECONOMY OF STEEL RAILS WITH LIGHT AND HEAVY HEADS.

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I shall consider the rail as consisting of two parts—the consumable part, all of which may be safely worn away; and the residuary part, which must not be worn at all, and which must be strong enough, after the consumable part is worn off, to carry the machinery safely. Of course, the consumable part—the *wearer*—is all in the upper part of the head. The residuary part—the *bearer*, consisting of the lower part of the head and of the stem and base—must be strong enough, after the consumable part is worn off, to carry the load safely.

The amount of strength required depends on the weight, inelasticity and speed of the machinery, the load upon a wheel, the distance apart and quality of the ties, and the condition of the road-bed. With iron rails, it is necessary to allow for the depreciation of the residuary part

of the head, and even of the stem and base, by the repeated concussions on the head; but with steel, owing to its elasticity and homogeneousness, and the absence of welds, no material deterioration of the residuary part takes place. A steel rail wears out; an iron rail is knocked to pieces before it is worn out.

Of course, when the rail is made heavier, the machinery and loads being constant, the different parts of the rail should not be increased proportionably, for that would give unnecessary weight to the residuary part, which we suppose to have been found strong enough already; but the additional weight should be put on the head, so as to be available for wear.

Commonly, on the same system of roads the same machinery is used and the same loads carried on the branches as on the main lines, and, therefore, the residuary rail must be strong in one case as in the other.

In planning a steel rail, the first thing to be done is to fix upon a residuary rail strong enough to carry safely the machinery and the load that are to run over it. Of course, the weights, speeds, springs, ties and road-bed, and possible increase of weights and speeds, must be taken into consideration. So many unknown quantities affect the question of strength required, that it cannot be found by calculation alone, but by experience, under the same or similar circumstances. The base should be broad enough not to crush or wear out the tie, and its area a little greater than that of the residuary part of the head. The stem should be as thin as experience has shown to be perfectly safe (for its thickness adds little to the strength of the rail); no existing circumstances require more than half an inch; but the usual height could be increased with advantage, for that would give opportunity to increase the strength of the splices.

The size of the consumable part of the rail will then be governed by the amount of traffic expected, taking also into consideration the greater wear per million of tons produced by greater weights on a wheel, higher speeds, poorer springs, steeper grades and sharper curves. The wear on a steep grade and sharp curve is sometimes as much as five times the wear of the same traffic on level tangents. Speaking generally, the consumable part of the rail should be proportioned to the amount of traffic, the residuary part to the weight on a wheel.

A small percentage of metal added to the head of most of the steel

rails in use adds a comparatively large percentage to their durability. In most cases, only about fifteen per cent. of the weight of the rail can be worn off from the head, all the rest—eighty-five per cent. of the whole original weight—being required to carry the load safely. By adding fifteen per cent. to the weight of such rails, putting it in the right place, their duration is doubled. On the other hand, interest must be paid on the cost of the additional metal before it comes into use at all during the whole time in which the original unincreased consumable quantity is wearing off. With heavy traffic, endurance; with light traffic, interest, is the weighty consideration.

I propose to give a very simple rule to find, between these conflicting considerations, the point of greatest economy, and to illustrate by the lightest steel rails used on main lines in the past, and by the heavier steel rails which are coming into use for the future.

The principles, and some of the formulæ, used in the following investigation were published, after careful consideration, in the journal of the Franklin Institute about ten years ago. I shall repeat so much of what was then written as may be necessary to make my calculations clear.

Much of the difficulty of such an investigation as this comes from the ambiguity of the term value. The intrinsic value of rails is measured by their capacity for usefulness; the exchangeable value is determined by that and the relative supply and demand, and the economic value, as I have called it, is measured by their combined capacity and opportunity for usefulness, under the actual circumstances where they are used. A heavy steel rail, laid in a car shed, has many times the intrinsic value of a light iron rail, but it has no more economic value, for, though it has the capacity, it has not the opportunity to do more than the iron rail in that situation can do just as well. A splendid hotel, in an inaccessible wilderness, might have ever so much intrinsic value or capacity for usefulness, but having no opportunity for usefulness, it would have no economic value; and there being all supply, and no demand, it would have no exchangeable value.

An engineer is likely to think of intrinsic value, a merchant of exchangeable, a shareholder of economic value.

Those who have ruined their employers by splendid engineering have commonly created capacity far in excess of opportunity for usefulness.

I shall use the term value only in its economic sense, that is, measured by combined capacity and opportunity for usefulness where the thing is actually used. This distinction is vital, and must be borne in mind.

I have, in all cases, reduced future usefulness and future expenses chargeable against it to present equivalents. All the values used are, therefore, present values.

In the present calculations, it is assumed that the traffic and the weight of machinery will continue uniform. It is easy, however, to apply the same processes and formulæ to cases where the traffic increases or diminishes.

It will be most convenient to consider the rails not by pounds per yard, but by tons to the mile, and the cost not per ton, but per mile.

The unit of cost and of value I shall use is that of a mile of rails laid down ready for use.

To facilitate the comparison of the values of rails of different durations with each other, I shall compare them both with the value of rails that, under the same circumstances, would last forever. The relations of the destructibles to the indestructible are simpler than that of the destructibles to each other.

We must assume, as a basis, that rails of some certain duration have, in the circumstances where used, a certain economic present value. The problem is to find the present economic value of those that in the same circumstances have some other duration. In the solution, we must take into consideration the rate of interest on cost and the loss in each case on renewal.

Let C be the cost of the rails in a mile of track, including hauling, handling, laying, and all other expenses, so as to be ready for use, which rails will last the time T, and which cost, in the present calculations, we shall suppose to be their true economic value; a, the rate of accumulated interest compounded every six months for that time; L, the loss on renewal with the same kind of rail, including all expenses, inconveniences, detentions and risks; and V the economic value of a mile of rails in the same circumstances that would last forever, inferred from the value of those that will last the time T. Also, let C' be the cost, and R the true economic present value for perpetuation of the rails that will last some other time, T', and L', the loss on their renewal, and a', the rate of accumulated interest for the time T'.

To make the rails that would last forever just as desirable at their valuation as the rails that will last the time T at their cost, the current charges against each, up to the end of that time, must be the same. The only charge against the indestructible is the accumulated interest on its valuation up to the end of that time, represented by aV. If the owner has borrowed the money, he has probably paid this interest annually, or semi-annually; but it amounts to the same thing as if he paid the compounded accumulated interest at the end of the period. Then the rails are just as they were at first, and the owner starts anew on the next period just as he did on the first. The current charge against the destructible rails for the same period consists of two parts, the accumulated interest on the cost, represented by aC, and the loss on renewal, L. After the renewal, the rails are just as they were at first, the owner has paid $a\,C + L$, and then enters on the next period just as he did on the first. The current charge against both being the same, we get the all-important equation, $aV = aC + L$. Dividing both sides of the equation by a, we get $V = C + \frac{L}{a}$.

Let R be the real economic value of the rails that will last some other time T', then, in the same manner as above, the current charge against them, up to end of that time, will be $a'R$ for interest and L' for the loss on renewal, the whole being $a'R + L'$, and then all is as it was at first. But the current charge for the same period against the indestructible rails is $a'V$; so that $a'V = a'R + L'$ and $V = R + \frac{L'}{a'}$ and $R = V - \frac{L'}{a'}$

As $V = C + \frac{L}{a}$, and also to $R + \frac{L'}{a'}$ $\therefore$ $R = C + \frac{L}{a} - \frac{L'}{a'}$.

V having unlimited capacity has unlimited intrinsic value; but its economic value is limited by its opportunities for usefulness, and that is in this case measured by the interest and expense with which destructible rails are chargeable, and which would be saved by the indestructible rails. Hence V is greater with a large than with a small tonnage, and greater where the loss on renewal is heavy than where it is light, for in the one case its opportunities of usefulness, or what amounts to the same thing, its savings of expense, are greater than in the other.

The economic value of R is increased by the durability of the rails, diminished by the greater interest charged against them. If the traffic

is heavy, the gain from their endurance is great; if the traffic is light, that gain may be more than overcome by heavy interest.

The foregoing formulæ, and the following tables and profiles, apply only to cases where the rails are for perpetuation, and not where the rails, when worn out, are to be replaced with some other kind. It is easy, however, to make a rule to find the value for replacement.

V and R are *present* values, and C and C' present costs, $\frac{L}{1+a}$ is the present value of the first renewal, and supposing traffic, interest and prices constant, $\frac{L}{a}$ is the present value of that renewal, and of all its successors forever.

If an absolutely indestructible rail could be got, the investment V would be greater than with R or C, and always continue so; but the absence of all cost of renewals would be equivalent to interest on the excess of investment.

Before we apply our principles, we must estimate as well as we can the facts we are to deal with, the amount of traffic, and its probable variations, the weight, speed, etc., of the machinery, the amount of metal worn off in that case per million tons of gross load, or the amount per annum, the cost of a mile of new track now, with rails of given weights, the loss on the renewals depending partly on what must be paid at the time for new rails and what can be got for the old, and whether all these things are constant or varying.

It may be asked, if we must depend on experience and judgment for all this data, why not for the settlement of the whole question? True, no rules of calculation can furnish data or supersede judgment in its proper sphere. True, there are many things such calculations cannot settle. But it is not so bad to mistake in data, as in data and inferences both. It is better to guess at only one thing than at two.

The first example I shall now give of the application of my rules is of rails substantially like those used on the Pennsylvania Railroad, the minimum weight being supposed to be 100 tons to the mile (= 63.636 pounds per yard). I have supposed that 15 tons per mile (= 9.666 pounds per yard) may safely be worn off, leaving the residuary rails 85 tons to the mile (= 53.97 pounds per yard). This will leave the area of what is left of the head somewhat less than the area of the base, and will carry the

heaviest machinery now coming into use. Wearing off 15 tons per mile would wear down the head about 0.45 of an inch, or each ton about 0.03.

I assume, of course, that where the rails are made heavier the whole additional metal is put upon the head, where all the wear comes. Little or nothing is gained by adding to the base and stem that are strong enough already.

I have estimated such rails laid down ready for use at $66.666 per ton or $6 666. per mile. Each additional stratum on the top of the rail, about 0.09 of an inch thick, weighing 3 tons per mile, will, then, cost $200.

Supposing prices continue the same, the renewal will cost $6 666. per mile, from which deduct the value of the old rails, and to which add the proper charge for detentions and inconveniences. I have estimated it for a track of 100 tons to the mile at $3 550, with an increase of $200 for each 3 tons per mile.

If, by the time of renewal, rails fall $10 per ton in price, then the loss on renewal will be lessened $1 000 by lower price of new rails, and increased $566 ($= \frac{2}{3} \times 10 \times 85$) by less price for old rails, making it $3 116. This will be represented by L_1. Each 3 tons weight of rails adds to this $170.

Or, if the rails should decline in price $20 per ton, the loss on renewal would be reduced $2 000 per mile, by less cost of new rails, and increased $1 133 ($= \frac{2}{3} \times 20 \times 85$) by less price for old rails, making $2 683. This will be represented by L_2. Each additional 3 tons increases it $140.

The economic values of V used in these calculations vary with the opportunities of usefulness, or saving expense, as follows :

	Interest.		
	5 Per Cent.	6 Per Cent.	7 Per Cent.
With prices constant $V =$.....	$12 222	$11 070	$10 252
With decline of $10 per ton $V_1 =$.....	11 542	10 532	9 813
With decline of $20 per ton $V_2 =$.....	10 865	9 995	9 376

I have appended tables showing the details of the data assumed, the steps of the calculations, and the results with different rates of interest, and under the different circumstances heretofore mentioned. I have also appended profiles showing the amount of saving by increase of weight.

It will be seen from the tables of results, and from the culminating points of the profiles, that where a 63½ pounds rail will last only 10 years, there is a decided gain in so increasing the weight that it shall last from 18 to 26 years. This is shown by the following synopsis. The greater part of the gain, however, is obtained by an increase much short of the maximum gain :

	Absolutely Greatest Saving.					Approaching Greatest Saving.			
Rate of Interest.	*T* Years.	Wt. per Mile, Tons.	Wt per Yd., Lbs.	Fall in Price of Rails.	Saving.	*T*.	Wt. Tons.	Wt. Lbs.	Saving.
5 Per Cent.	26	124	78.9	$ 0	$1 984	22	118	75.1	$1 937
"	24	121	77.	10	1 581	20	115	73.2	1 522
"	22	118	75.1	20	1 205	20	115	73.2	1 191
6 Per Cent.	22	118	75.1	0	1 416	20	115	73.2	1 393
"	22	118	75.1	10	1 118	18	112	71.3	1 066
"	20	115	73.2	20	833	18	112	71.3	820
7 Per Cent.	20	115	73.2	0	1 049	18	112	71.3	1 010
"	20	115	73.2	10	807	18	112	71.3	798
"	18	112	71.3	20	586	16	109	69.4	564

We should not miss it much by saying that on a road where a 63½ pounds rail will wear only 10 years, the most economical size is about 72 pounds per yard, but that two-thirds of the greatest gain is attained by increasing to 67 pounds per yard.

One objection to such a rail is the increased disproportion between the head and base, increasing the difficulty of cooling without strain, after rolling.

Other considerations, which it is not my present purpose to refer to, will in many cases control.

The largest traffic, heaviest machinery, lowest interest, and greatest inconvenience of renewal call for the heaviest rail, the smaller traffic, lighter machinery, higher interest, and probable future decline in the price of rails call for lighter rails.

All these calculations contemplate constant traffic. If it increases, as is in most cases probable, it is an argument in favor of heavier rails.

Though the weight of rail and the time of greatest saving is so near the same in all cases, the amount of saving by increased weight varies very much. The lowest interest and highest future price give the greatest saving. At 5 per cent. and prices constant, the greatest saving is $1 984, with future prices $20 lower, $1 205. At 6 per cent. and prices constant, the greatest saving $1 426, or with decline of $20, $833. At 7 per cent. and prices constant, the greatest saving is $1 049, or with decline of $20, $567.

I have added a table to show what gain there is, in increasing the size of 63¾ lb. rail on a road where it will last twenty years. Even with money at 5 per cent. and prices constant, the gain by increase is small, and when money is 7 per cent. and prices decline $20, there is no gain.

I may be asked why I have adopted, as an example, a rail whose residuary portion is 53 lbs., when, in 1867, I laid 53 lb. steel rails on the main line between New York and Philadelphia, which were only taken out in 1880, and some of which were worn down to 46 lbs. per yard; and when 56 lb. rails were laid on the line between Philadelphia and Baltimore, in 1868, and are still in the track, and after the lapse of a dozen years, are still in good order, and when on another road, 56 lb. rails now carrying 100 000 tons of coal per month, are worn down to 45 to 46 lbs. per yard, and when many important lines are laid with 56 lb. rails.

My answer is, that the increasing weight of machinery and of the loads carried have induced the great trunk lines to adopt the heavier rail. The maximum weight on a freight car wheel has been increased from 5 000 to 8 000 lbs., and on a locomotive driving wheel from 10 000 to 15 000 lbs., or even more. It seemed, therefore, proper that our example should be taken from this heavy class. But I have also given calculations for the 53 lb. rail.

If as good steel can be got now as formerly, a road of moderate traffic may be laid with 53 lb. rails. But the machinery must be adapted to it.

It will not do for a committee of the directors to buy an engine and put it on the road, because it will haul a big load, without knowing whether the rails are strong enough to carry it or not.

A size of rail which it was wise to adopt a few years ago, when American companies paid full 7 per cent. interest, when money was scarce, credit poor, traffic small, machinery and loads light, speeds slower, steel high but falling in price and, perhaps, in quality, it might be unwise to adopt now on great thoroughfares, when all these circumstances are reversed.

Suppose a rail 53.03 pounds to the yard = 83.33 tons to the mile, and on a road where it will last ten years, losing in that time 1.125 tons per year, or 11.25 tons in all; and leaving the residuary rail 72.08 tons per mile = 45.87 lbs. per yard. It will thus wear down about 0.0333 inches per year, and lose 0.716 lbs. per yard per year, or 7.16 in all.

If prices remain constant, and rails cost 66.66 per ton in finished tracks, the additional cost to make it last two additional years is $150 per mile, and the increased cost of renewal the same. If the price of rails falls $10 per ton, the cost of renewal is reduced from $3 000 to 2 647 per mile, with an increase of $125 for metal for each two years additional duration. If prices decline $20 per ton, the cost of renewal is reduced to $2 294, with an increase of $100 for metal to increase the durability two years. All which is shown in the tables.

Thus far I have supposed each kind of rails to be perpetuated. Now, suppose the $63\frac{2}{3}$ lb. rails before considered, instead of being perpetuated, are only renewed one, two or three times. The loss on renewal being $3 550, the cost of it is 3 116. The present value of the cost of renewal is $3\ 116 \div 1 + a$. In the following table the first column is years; the second, cost of rail that will last those years; the third and sixth, present value of cost of renewal of rails that last ten years; the fourth and seventh, the aggregate of all cost of short lived rails; the fifth and eighth, the saving on the long lived rails.

T Years.	Cost of Rails Lasting those Years.	Interest, 5 per cent.			Interest 7 per cent.		
		Pr. Value Cost of Renewal.	Aggregate Pr. Value of all cost Short Lived Rails.	Gain by Larger Rails.	Pr. Value of Cost of Renewal.	Pr. Value all Cost of Smaller Rails.	Gain by Larger Rails.
10	6 666	.....	6 666	.....	.....	6 666	.....
20	7 666	1 902	8 568	902	1 569	8 235	569
30	8 666	1 160	9 728	1 062	787	9 022	356
40	9 666	440	10 168	502	396	9 418	— 248

The cases supposed and inferences from them, are given as examples of the application of rules that are very simple, and that I have found very convenient. They also show some striking results. They are applicable in the comparison of many cheap and short lived things with more costly and durable things, between which the engineer is often called to choose—such as wooden and iron bridges. To save a good deal of labor to those who wish to use these rules, I have appended a table of the rates of accumulated interest at 5, 6, and 7 per cent.

Symbols used in the following tables:

Capital letters used to represent the $63\frac{2}{3}$ lb. rails, and for distinction, small letters to represent the 53 lb. rails.

a. Rate of accumulated interest.

d. Depth of consumable part of head.

w. Weight in tons per mile.

T. Time the rails will last.

C. Cost per mile laid.

L. Loss per mile on renewal if prices constant.

L_1. Loss on renewal if price declines $10 per ton.

L_2. Loss on renewal if price declines $20 per ton.

R. Real value per mile of enlarged rails, prices constant.

R_1. Real value if price declines $10 per ton.

R_2. Real value if price declines $20 per ton.

S. Saving by enlarging rails $= R - C^1$, price constant.

S_1. Saving if price declines $10, $= R_1 - C^1$.

S_2. Saving if price declines $20, $= R_2 - C^1$.

TABLE 1.—DATA ASSUMED WITH THE $63\frac{2}{3}$ LB. RAILS, WHERE THEY WILL LAST TEN YEARS, AND THEN BE REDUCED IN WEIGHT 15 PER CENT. FOR MEANING OF SYMBOLS SEE P. 261.

$T.$	$d.$	$w.$	$C.$	$L.$	$L_1.$	$L_2.$
10	0.45	100	6666	3550	3116	2683
12	0.54	103	6866	3750	3286	2823
14	0.63	106	7066	3950	3456	2963
16	0.72	109	7266	4150	3626	3103
18	0.81	112	7466	4350	3796	3243
20	0.90	115	7666	4550	3966	3383
22	0.99	118	7866	4750	4136	3523
24	1.08	121	8066	4950	4306	3663
26	1.17	124	8266	5150	4476	3803
28	1.26	127	8466	5350	4646	3943
30	1.35	130	8666	5550	4816	4083
32	1.44	133	8866	5750	4986	4223
34	1.53	136	9066	5950	5156	4363
36	1.62	139	9266	6150	5326	4503
38	1.71	142	9466	6350	5496	4643
40	1.80	145	9666	6550	5666	4783
44	1.98	151	10066	6950	6006	5063
48	2.16	157	10466	7350	6346	5343
52	2.34	163	10866	7750	6686	5623
56	2.62	169	11266	8150	7026	5903
60	2.70	175	11666	8550	7366	6183

TABLE 2.—CALCULATIONS OF THE $63\frac{2}{3}$ LB. RAILS. INTEREST 5 PER CENT.

$T.$	a	$\frac{L}{a}$	$\frac{L_1}{a}$	$\frac{L_2}{a}$
10	0.639	5556	4876	4199
12	0.808	4641	4067	3494
14	0.996	3966	3470	2975
16	1.204	3447	3012	2577
18	1.432	3038	2651	2265
20	1.685	2700	2354	2008
22	1.964	2419	2106	1794
24	2.272	2179	1895	1612
26	2.611	1972	1714	1457
28	2.986	1792	1556	1320
30	3.400	1632	1416	1201
32	3.857	1491	1293	1095
34	4.361	1364	1182	1000
36	4.917	1251	1083	916
38	5.532	1148	993	839
40	6.210	1055	912	770
42	6.956	970	839	708
44	7.784	893	772	650
46	8.696	822	710	598
48	9.703	757	654	551
50	10.814	698	603	507
52	12.040	644	555	467
54	13.394	594	512	430
56	14.888	547	472	396
58	16.538	505	435	365
60	18.358	466	401	337

TABLE 3.--CALCULATIONS WITH THE $63\frac{2}{3}$ LB. RAILS. INTEREST 6 PER CENT.

T	a	$\frac{L}{a}$	$\frac{L_1}{a}$	$\frac{L_2}{a}$
10	0.806	4404	3866	3329
12	1.033	3630	3181	2733
14	1.288	3067	2683	2300
16	1.575	2635	2302	1970
18	1.898	2292	2000	1709
20	2.262	2011	1753	1496
22	2.671	1778	1548	1319
24	3.132	1580	1375	1170
26	3.651	1411	1226	1042
28	4.235	1263	1097	931
30	4.892	1135	984	835
32	5.631	1021	885	750
34	6.463	921	798	675
36	7.400	831	720	609
38	8.454	751	650	549
40	9.641	679	588	496
42	10.976	615	532	449
44	12.480	557	481	406
46	14.171	505	436	367
48	16.076	457	395	332
50	18.219	414	358	301
52	20.63	376	324	273
54	23.345	341	294	247
56	26.401	309	266	224
58	29.84	280	241	203
60	33.711	254	219	183

TABLE 4.—CALCULATIONS WITH THE 63⅔ LB. RAILS. INTEREST 7 PER CENT.

T	a	$\frac{L}{a}$	$\frac{L_1}{a}$	$\frac{L_2}{a}$
10	0.990	3586	3147	2710
12	1.283	2923	2561	2200
14	1.620	2438	2133	1829
16	2.007	2068	1807	1546
18	2.450	1776	1549	1324
20	2.960	1537	1340	1143
22	3.543	1341	1167	994
24	4.214	1175	1022	869
26	4.983	1034	898	763
28	5.865	912	792	672
30	6.878	807	700	594
32	8.040	715	620	525
34	9.374	635	550	465
36	10.904	564	488	413
38	12.66	502	434	367
40	14.676	446	386	326
42	16.988	397	344	290
44	19.642	354	306	258
46	22.687	315	272	229
48	26.181	281	242	204
50	30.191	250	216	182
52	34.792	223	192	162
54	40.073	198	171	144
56	46.132	177	152	128
58	53.085	157	136	114
60	61.063	140	121	101

TABLE 5.—RESULTS WITH THE 63⅔ LB. RAILS. INTEREST 5 PER CENT.

T	C	R	$S=R-C'$	R_1	$S_1=R_1-C'$	R_2	$S_2=R_2-C'$
10	6666	6666					
12	6866	7581	715	7475	609	7371	505
14	7066	8256	1190	8072	1006	7890	824
16	7266	8775	1509	8530	1264	8288	1022
18	7466	9184	1718	8891	1425	8600	1134
20	7666	9522	1856	9188	1522	8857	1191
22	7866	9803	1937	9436	1570	9071	1205
24	8066	10043	1977	9647	1581	9253	1187
26	8266	10250	1984	9828	1562	9408	1142
28	8466	10430	1964	9986	1520	9545	1079
30	8666	10590	1924	10126	1460	9664	998
32	8866	10731	1865	10249	1383	9770	904
34	9066	10858	1792	10360	1294	9865	799
36	9266	10971	1705	10459	1193	9949	683
38	9466	11074	1608	10549	1083	10026	560
40	9666	11167	1501	10630	964	10095	429
42	9866	11252	1386	10703	837	10157	291
44	10066	11329	1263	10770	704	10215	149
46	10266	11400	1134	10832	566	10267	1
48	10466	11465	999	10888	422	10314	—152
50	10666	11524	858	10939	273	10358	—308
52	10866	11578	712	10987	121	10398	—468
54	11066	11628	562	11030	—36	10435	—631
56	11266	11675	409	11070	—196	10469	—797
58	11466	11717	251	11107	—359	10500	—966
60	11666	11756	90	11141	—525	10528	—1138

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PLATE XXXIX
TRANS. AM. SOC. CIV. ENGR'S.
VOL. X. Nº CCXXV.
WELCH
ON ECONOMY OF STEEL RAILS

PROFILE OF SAVINGS BY INCREASING THE DEPTH OF THE HEAD OF THE 63½ lbs. RAILS ON A ROAD WHERE UNINCREASED THEY WILL LAST 10 YEARS. TRAFFIC AND PRICES SUPPOSED CONSTANT. COMPARISON WITH INTEREST AT 5, 6 AND 7 PER CENT.

TABLE 6.—RESULTS WITH THE 63⅔ LB. RAILS. INTEREST 6 PER CENT.

T	C	R	$S = R - C'$	R_1	$S_1 = R_1 - C'$	R_2	$S_2 = R_2 - C'$
10	6666	6666					
12	6866	7440	574	7351	485	7262	396
14	7066	8003	937	7849	783	7695	629
16	7266	8435	1169	8230	964	8025	759
18	7466	8778	1312	8532	1066	8286	820
20	7666	9059	1393	8779	1113	8499	833
22	7866	9292	1426	8984	1118	8676	810
24	8066	9490	1424	9157	1091	8825	759
26	8266	9659	1393	9306	1040	8953	687
28	8466	9807	1341	9435	969	9064	598
30	8666	9935	1269	9548	882	9160	494
32	8866	10049	1183	9647	781	9245	379
34	9066	10149	1083	9734	668	9320	254
36	9266	10239	973	9812	546	9386	120
38	9466	10319	853	9882	416	9446	—20
40	9666	10391	725	9944	278	9499	—167
42	9866	10455	589	10000	134	9546	—320
44	10066	10513	447	10051	—15	9589	—477
46	10266	10565	299	10096	—170	9628	—638
48	10466	10613	147	10137	—329	9663	—803
50	10666	10656	—10	10174	—492	9694	—972
52	10866	10694	—172	10208	—658	9722	—1144
54	11066	10729	—337	10238	—828	9748	—1318
56	11266	10761	—505	10266	—1000	9771	—1495
58	11466	10790	—676	10291	—1175	9792	—1674
60	11666	10816	—850	10313	—1353	9812	—1854

TABLE 7.—RESULTS WITH THE 63⅔ LB. RAILS. INTEREST 7 PER CENT.

T	C	R	$S = R - C'$	R_1	$S_1 = R_1 - C'$	R_2	$S_2 = R_2 - C'$
10	6666	6666	.....	.....	.....	.....	.....
12	6866	7329	463	7252	386	7176	310
14	7066	7814	748	7680	614	7547	481
16	7266	8184	918	8006	740	7830	564
18	7466	8476	1010	8264	798	8052	586
20	7666	8715	1049	8473	807	8233	567
22	7866	8911	1045	8646	780	8382	516
24	8066	9077	1011	8791	725	8507	441
26	8266	9218	952	8915	649	8613	347
28	8466	9340	874	9021	555	8704	238
30	8666	9445	779	9113	447	8782	116
32	8866	9537	671	9193	327	8851	—15
34	9066	9617	551	9263	197	8911	—155
36	9266	9688	422	9325	59	8963	—303
38	9466	9750	284	9379	—87	9009	—457
40	9666	9806	140	9427	—239	9050	—616
42	9866	9855	—11	9469	—397	9086	—780
44	10066	9898	—168	9507	—559	9118	—948
46	10266	9937	—329	9541	—725	9147	—1119
48	10466	9971	—495	9571	—895	9172	—1294
50	10666	10002	—664	9597	—1069	9194	—1472
52	10866	10029	—837	9621	—1245	9214	—1652
54	11066	10054	—1012	9642	—1424	9232	—1834
56	11266	10075	—1191	9661	—1605	9248	—2018
58	11466	10095	—1371	9677	—1789	9262	—2204
60	11666	10112	—1554	9692	—1974	9275	—2391

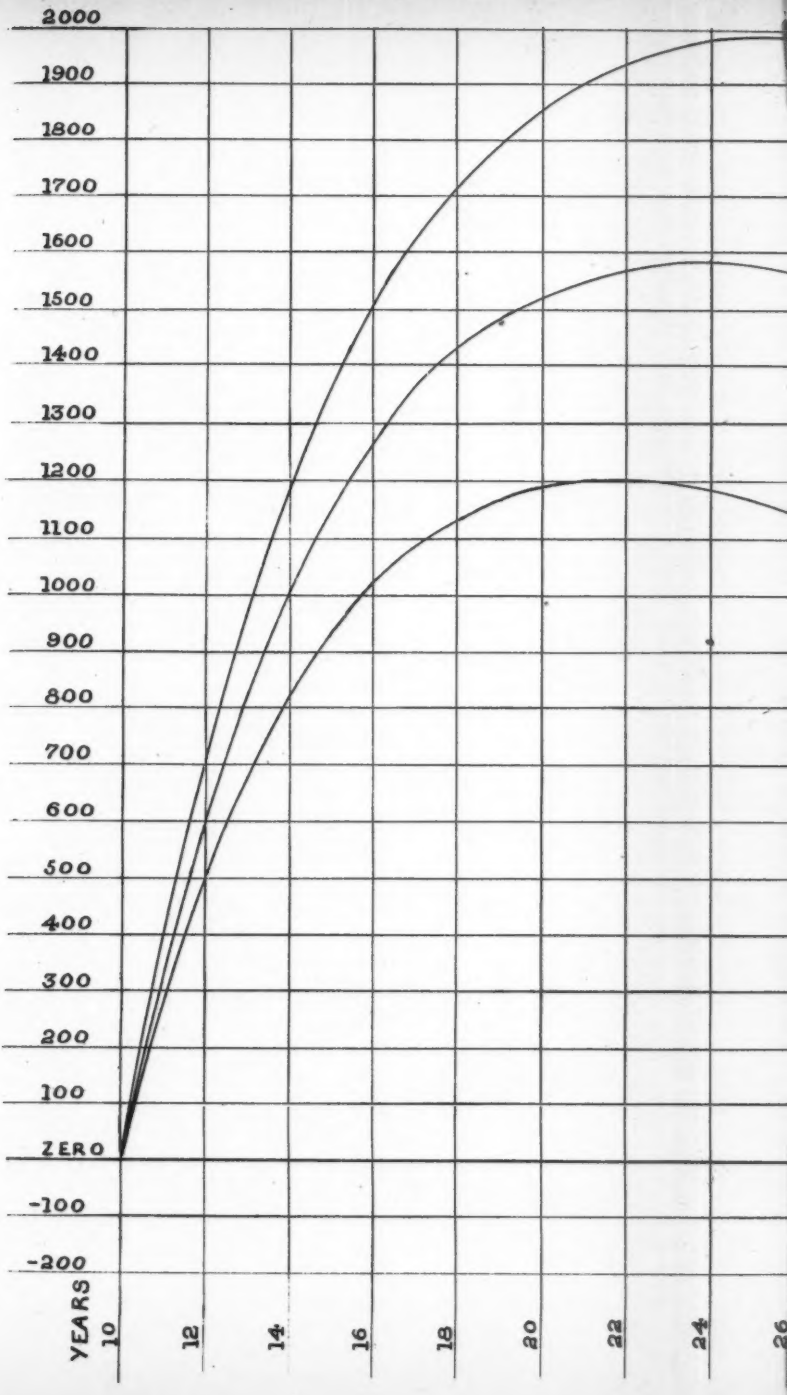
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PLATE XL.
TRANS. AM. SOC. CIV. ENGRS.
VOL. X. Nº CCXXV.
WELCH
ON ECONOMY OF STEEL RAILS

PROFILE OF SAVINGS BY INCREASING THE DEPTH OF THE HEAD OF THE 63 2/3 lbs RAILS ON A ROAD WHERE UNINCREASED THEY WILL LAST 10 YEARS. S, SUPPOSING PRICES CONSTANT; S_1, A DECLINE BEFORE RENEWAL OF $10 PER TON; S_2, A DECLINE OF $20. INTEREST 5 PER CENT

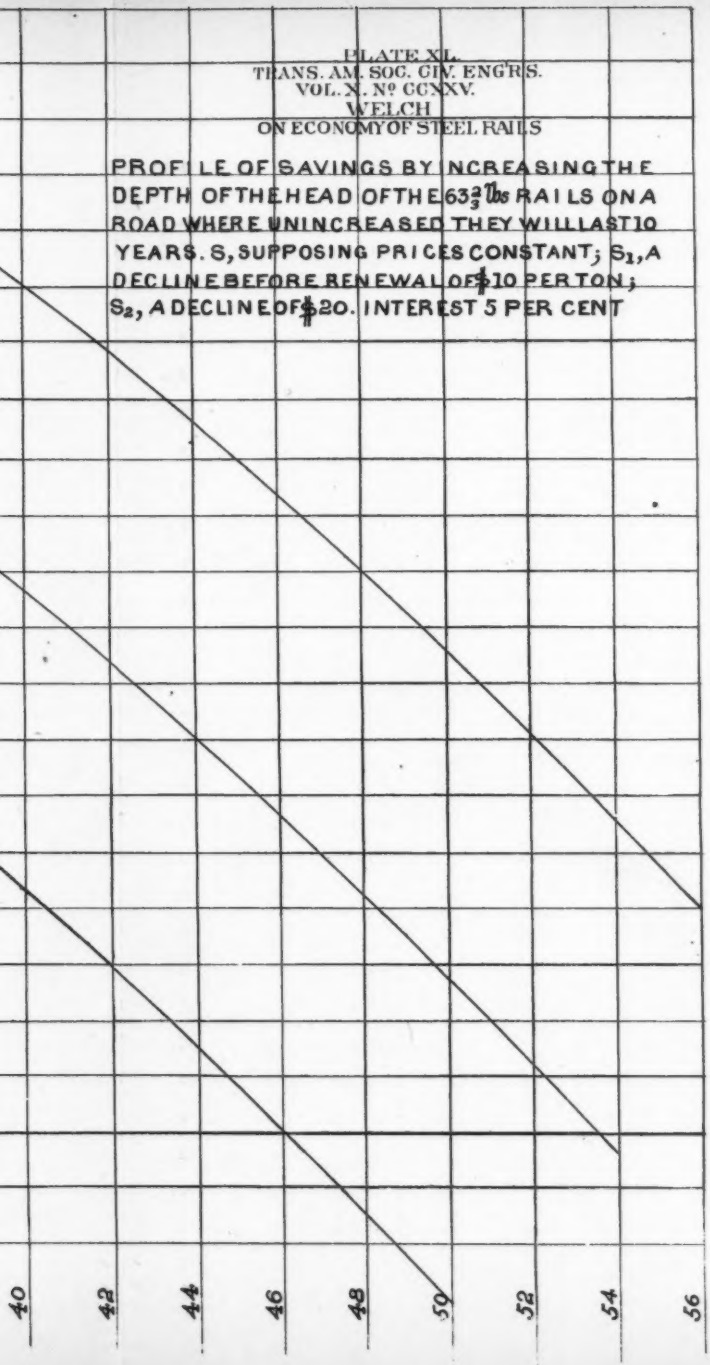

TABLE 8.—Results with Prices Constant where a 63½ lb. Rail lasts 20 Years.

$V = 8779$.

T	a	L	$\frac{L}{a}$	R	C	S	
20	1.68	3550	2113	.....	6666	.....	Interest 5 per cent.
24	2.27	3750	1582	7197	6866	331	
28	2.99	3950	1321	7458	7066	392	
32	3.86	4150	1075	7704	7266	438	
36	4.92	4350	884	7895	7466	429	
40	6.21	4550	733	8046	7666	380	
44	7.78	4750	610	8169	7866	303	
48	9.70	4950	510	8269	8066	203	

$V = 8237$.

20	2.26	3550	1571	.....	6666	.....	Interest 6 per cent.
24	3.13	3750	1198	7037	6866	171	
28	4.23	3950	934	7303	7066	237	
32	5.63	4150	737	7500	7266	234	
36	7.40	4350	584	7653	7466	187	
40	7.64	4550	478	7764	7666	98	
44	12.48	4750	380	7857	7866	— 9	
48	16.08	4950	308	7929	8066	—137	

$V = 7866$.

20	2.96	3550	1200	.....	6666	.....	Interest 7 per cent.
24	4.21	3750	891	6973	6866	109	
28	5.87	3950	673	7193	7066	127	
32	8.04	4150	516	7350	7266	84	
36	10.90	4350	400	7466	7466	0	
40	14.68	4550	300	7566	7666	—100	
44	19.64	4750	242	7624	7866	—242	

TABLE 9.—RESULTS—RAIL OF 63⅔ LBS. LASTING 20 YEARS. INTEREST 7 PER CENT. DECLINE $20.

$V = 7569.$

T	W	a	L_2	$\frac{L_2}{a}$	R_2	C	S_2
20	100	2.96	2683	903	.....	6666	.....
24	103	4.21	2823	670	6899	6866	33
28	106	5.87	2963	504	7065	7066	—1
32	109	8.04	3103	386	7183	7266	—83
36	112	10.90	3243	300	7269	7466	—197
40	115	14.68	3383	230	7339	7666	—327

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PLATE XLI.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. X. Nº CCXXV.
WELCH
ON ECONOMY OF STEEL RAILS

SAVINGS BY INCREASING THE DEPTH OF
F THE 63½ lbs RAILS ON A ROAD WHERE
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STANT; S_1, A DECLINE BEFORE RENEWAL OF
; S_2 A DECLINE OF $20. INTEREST 6 PER CENT

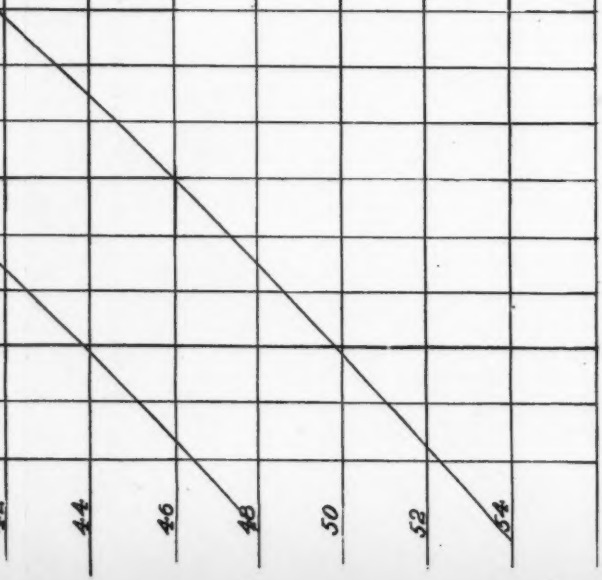

TABLE 10.—DATA WITH 53.03 LB. RAIL—LASTS 10 YEARS—RESIDUARY 45.87 LBS.

$T.$	$d.$	$w.$	$c.$	$l.$	l_1	$l_2.$
10	.333	83.33	5555	3000	2647	2294
12	.400	85.58	5705	3150	2777	2394
14	.466	87.83	5855	3300	2897	2494
16	.533	90.08	6005	3450	3022	2594
18	.600	92.33	6155	3600	3147	2694
20	.666	94.58	6305	3750	3272	2794
22	.733	96.83	6455	3900	3397	2894
24	.800	99.08	6605	4050	3522	2994
26	.866	101.33	6755	4200	3647	3094
28	.933	103.58	6905	4350	3772	3194
30	1.000	105.83	7055	4500	3897	3294
32	1.066	108.08	7205	4650	4022	3394
34	1.133	110.33	7355	4800	4147	3494
36	1.200	112.58	7505	4950	4272	3594
38	1.266	114.83	7655	5100	4397	3694
40	1.333	117.08	7805	5250	4522	3794
42	1.400	119.33	7955	5400	4647	3894
44	1.466	121.58	8105	5550	4772	3994
46	1.533	123.83	8255	5700	4897	4094
48	1.600	126.08	8405	5850	5022	4194
50	1.666	128.33	8555	6000	5147	4294

TABLE 11.—Calculations 53.03 lb. Rail. Interest 5 per cent.

T	a	$\frac{l}{a}$	$\frac{l_1}{a}$	$\frac{l_2}{a}$	
10	0.639	4695	4142	3590	c — 5,555
12	0.808	3899	3431	2963	v — 10,250
14	0.996	3313	2909	2504	v_1 — 9,697
16	1.204	2865	2510	2154	v_2 — 9,145
18	1.432	2514	2198	1881	
20	1.685	2226	1942	1657	
22	1.964	1986	1730	1473	
24	2.272	1783	1550	1318	
26	2.611	1609	1397	1185	
28	2.886	1457	1263	1070	
30	3.400	1324	1146	969	
32	3.857	1206	1043	880	
34	4.361	1101	951	801	
36	4.917	1007	869	731	
38	5.532	922	795	668	
40	6.210	845	728	611	
42	6.956	776	668	560	
44	7.784	713	613	513	
46	8.696	656	563	471	
48	9.703	603	518	432	
50	10.814	555	476	397	

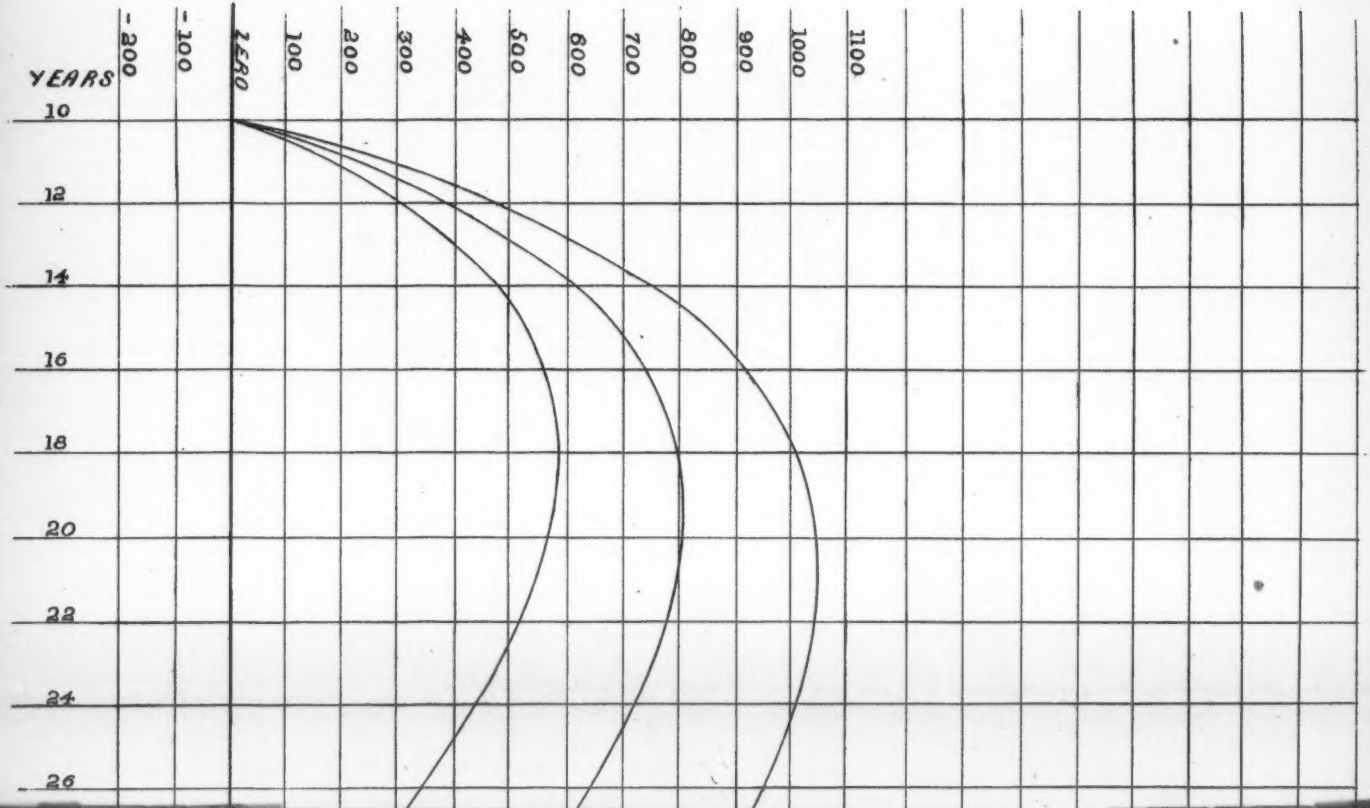
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PLATE XLII.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. X. Nº CCXXVII.
WELCH
ON ECONOMY OF STEEL RAILS

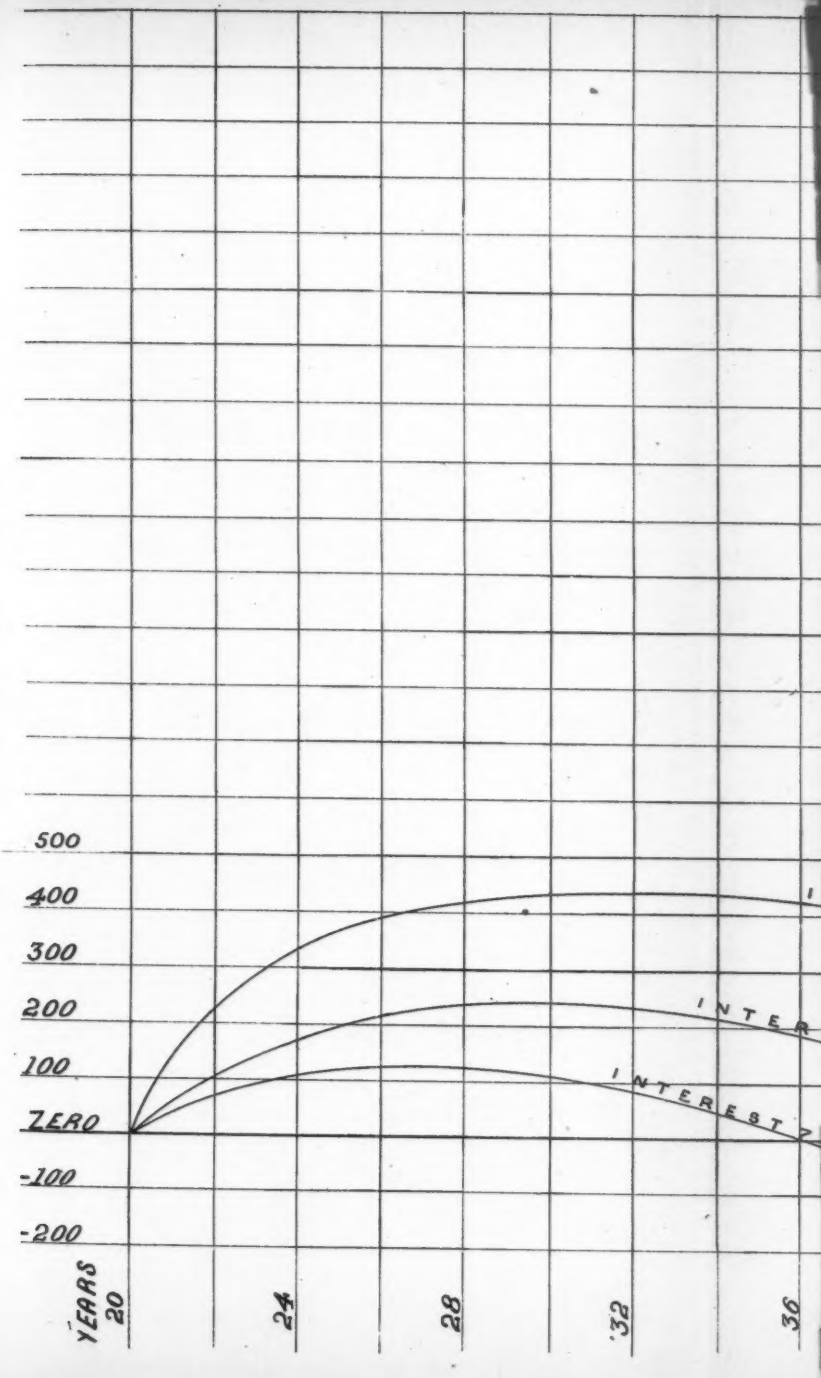
OF SAVINGS BY INCREASING THE DEPTH OF
D OF THE 65 3/4 lb RAILS ON A ROAD WHERE
EASED THEY WILL LAST 10 YEARS; S, SUPPOSING
CONSTANT; S_1, A DECLINE BEFORE RENEWAL
RTON; S_2, A DECLINE OF $\frac{1}{4}$ 20. INTEREST 7 PER CENT.

TABLE 12.—TABLE OF RESULTS WITH 53.03 LB. RAILS.—INTEREST 5 PER CENT.

T	c.	r	$s = r - c$	r_1	$s_1 = r_1 - c'$	r_2	$s_2 = r_2 - c'$
10	5555						
12	5705	6351	646	6266	561	6182	477
14	5855	6937	1082	6788	933	6641	786
16	6005	7385	1380	7187	1182	6991	986
18	6155	7736	1581	7499	1344	7264	1109
20	6305	8024	1719	7755	1450	7488	1183
22	6455	8264	1809	7967	1512	7672	1217
24	6605	8467	1862	8147	1542	7827	1222
26	6755	8641	1886	8300	1545	7960	1205
28	6905	8793	1888	8434	1529	8075	1170
30	7055	8926	1871	8551	1496	8176	1121
32	7205	9044	1839	8654	1449	8263	1060
34	7355	9149	1794	8746	1391	8344	989
36	7505	9243	1738	8828	1323	8414	909
38	7655	9328	1673	8902	1247	8477	822
40	7805	9405	1600	8969	1164	8534	729
42	7955	9474	1519	9029	1074	8585	630
44	8105	9537	1432	9084	979	8632	527
46	8255	9594	1339	9134	879	8674	419
48	8405	9647	1242	9179	774	8713	308
50	8555	9695	1140	9221	666	8748	193

TABLE 13.—Rates of Accumulated Interest.

	5 p. c.	6 p. c.	7 p. c.		5 p. c.	6 p. c.	7 p. c.
½	0.0250	0.0300	0.0350	42	6.9562	10.9760	16.988
1	0.0506	0.0609	0.0712	44	7.7842	12.4800	19.642
2	0.1038	0.1255	0.1475	46	8.6961	14.171	22.687
4	0.2184	0.2668	0.3168	48	9.703	16.076	26.181
6	0.3449	0.4258	0.5111	50	10.814	18.219	30.191
8	0.4845	0.6047	0.7340				
10	0.6386	0.8061	0.9898	60	18.358	33.711	61.063
12	0.8087	1.0328	1.2833	70	30.721	61.691	122.49
14	0.9965	1.2879	1.6202	80	50.979	112.23	244.72
16	1.2038	1 5751	2.0067	90	84.173	203.50	487.94
18	1.4325	1.8983	2.4503	100	138.57	368.35	971.88
20	1.6851	2.2620	2.9593				
22	1.9638	2.6714	3.5433				
24	2.2715	3.1322	4.2136				
26	2.6111	3.6509	4.9827				
28	2.9860	4.2346	5.8653				
30	3.3998	4.8916	6.8780				
32	3.8566	5.6310	8.0402				
34	4.3607	6.4633	9.3740				
36	4.9173	7.4000	10.9040				
38	5.5316	8.4543	12.6600				
40	6.2096	9.6410	14.6760				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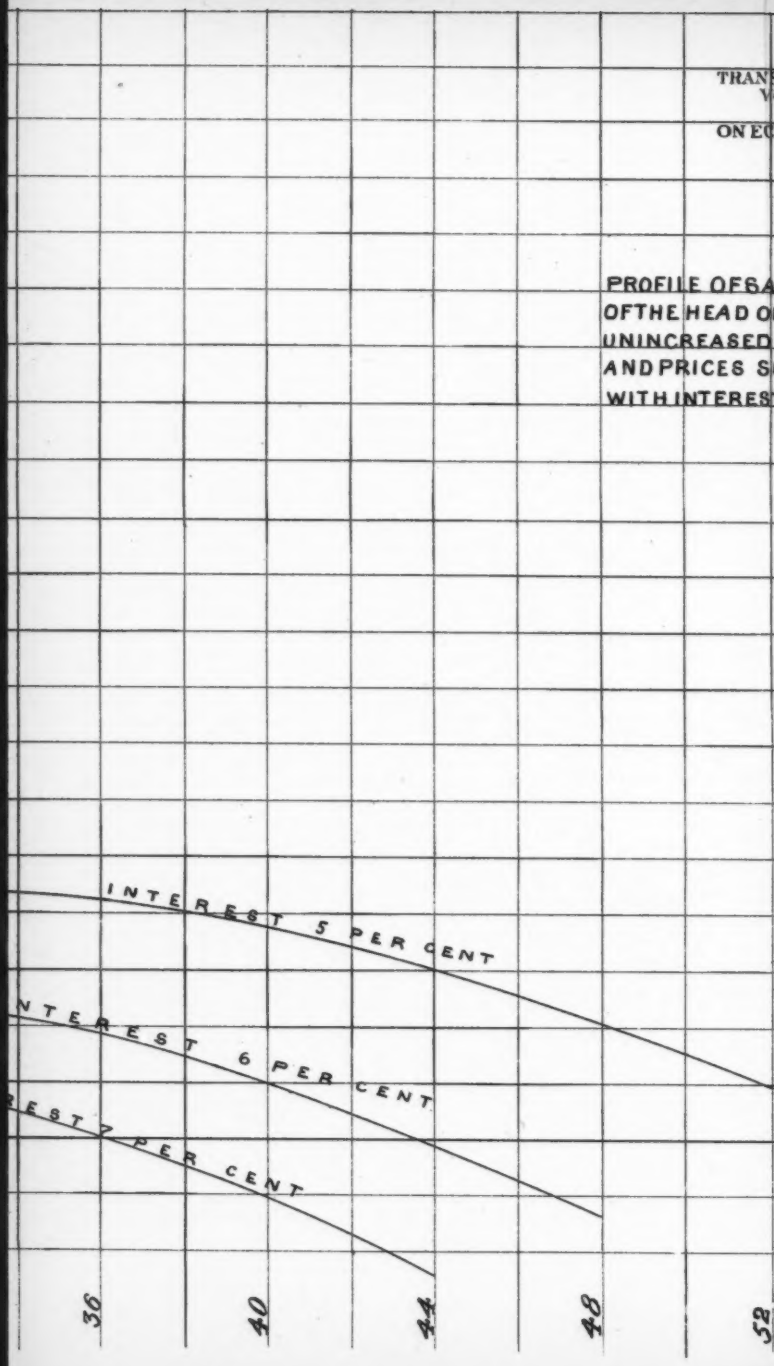
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PLATE XLIII.
TRANS. AM. SOC. CIV. ENG'R'S.
VOL. X. N° CCXXV.
WELCH
ON ECONOMY OF STEEL RAILS

E OF SAVINGS BY INCREASING THE DEPTH
HEAD OF THE 63 3/5 lbs RAILS ON A ROAD WHERE
EASED THEY WILL LAST 20 YEARS. TRAFFIC
ICES SUPPOSED CONSTANT. COMPARISON
NTEREST AT 5, 6 AND 7 PER CENT.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

TRANSACTIONS.

CCXXVI.

Vol. X.—August, 1881.

QUICKSAND IN EXCAVATION.

By Charles L. McAlpine, Member of the Society.

Read May 18, 1881.

WITH DISCUSSION

By William R. Hutton, Member of the Society.

Particular attention has been given, and expressed by members of the Society and others, in writing, and orally, as to the various materials encountered in the prosecution of work; yet little has been recorded of the material of which this paper is the subject.

The various text-books are silent in regard to the economic management of this, one of the most troublesome materials that an engineer is called upon to deal with.

Those who have encountered it would have been greatly aided by the experience, now only contained in private note-books or the recollections of the profession.

With this in view, the writer offers to the Society some memoranda and a description of the methods used several years since, in the excavation and removal of a large body of quicksand, prefacing that two energetic and experienced contractors successively failed in their attempts by the ordinary methods used for removing earth excavation.

As these failures had given the place a bad name among contractors, and no one was found willing, except at excessive prices, to undertake the work, the writer, then in charge, urged and obtained from the State authorities of New York the power to conduct it personally.

Omitting mention of minor difficulties, only the principal ones will be here considered.

A mass of quicksand occurred in a cutting on the State works of New York, of about thirteen hundred feet in length, and averaging about thirty feet in depth, amounting in the aggregate to one hundred thousand cubic yards—although a portion of the cutting was what is known as cemented clay and gravel (sometimes called hard-pan), occurring in layers or strata at different elevations, the remainder being ordinary earth excavation.

About forty thousand cubic yards had been removed by the contractor, or was other than quicksand, leaving sixty thousand cubic yards of the latter material.

No change of location was admissible.

The contractors' methods had been to work off as much material as possible at the ends and top of the cutting, using heavy plows, especially constructed, requiring in some cases eight to ten horses in order to break it up for the shovel. Some attention had been also paid to drainage.

A breast and falls had been attempted at one end, in the usual manner for ordinary earth, but the material remained quicksand, despite some attempts to reduce it to a less expensive condition.

It was no infrequent occurrence to see laborers, animals, contractor and engineers stuck fast in the mud together—some of them extracted with no little difficulty—and a visitor to this section always brought away with him distinguishing marks of his trip.

When the execution of the work passed into the hands of the engineer, the key-note was considered to be a most thorough and complete system of drainage, as nearly all of the difficulties met with were directly traceable to the excessive amount of water which this

peculiar material is capable of retaining, and drawing to itself through capillary attraction or other natural laws, and which it very reluctantly parts with.

Although its name conveys the idea of a mass of sand, surcharged with water until it becomes "quick," or susceptible of easy movement or agitation, suggesting actual life, yet engineers know only too well that this is not the most troublesome member of the family.

The one that causes the most trouble, and is here treated of, is an argillaceous material containing no silex or grit, comminutes completely, and is usually leaden in color in its natural state, and nearly white when thoroughly deprived of water.

So free is it from sand that it can be used with good effect in polishing or cleaning silver and the softer metals.

The work was therefore commenced by driving a cutting into the middle of the quicksand and at right angles to the canal prism, with a grade below canal bottom, and amply below the level necessary for good and rapid drainage.

The comparative magnitude of this drainage cutting, amounting to nine thousand cubic yards, to be made at their own cost, had deterred the contractors from attempting it.

To this main drain other large ones were conducted, over the surface of the cutting intended for the prism.

The top width of the prism cutting was about one hundred and fifty feet.

Connecting with these large drains were innumerable smaller ones, made to reach all parts of the surface of the quicksand.

Such drainage as could be effected from each end of the cutting was also availed of.

The construction and maintenance of these ditches, in first rate effective order, was in reality the key to the success of the plan, but with continued practice it was remarkable how efficient the workmen became in this troublesome part of the work.

By an occasional judicious use of the plow or scraper, but mainly, however, with spades and shovels, providing planks for the men to stand on while at work, and the selection of intelligent workmen, the cost and time required were soon much reduced.

As far as possible, all traveling over the surface while being thus ditched was prevented, as it agitated the material, and caused it to retain the water more obstinately.

After a night's quiet rest, and the great withdrawal of water through the ditches, the surface was in good condition for excavating and the material, in the words of the workmen, would then "shovel like ashes."

As far as possible, plank roads were laid for the carts, and by frequently shifting from one place to another, the parts to be worked were given sufficient time to drain, and they had also been given the undisturbed *rest* which this material requires.

Care should always be had to withdraw the men and teams at once from any place which indicates that it is again becoming "quick," from the disturbing effect of repeated traveling over its surface.

Nothing is gained by working longer, when this important question of rest is involved.

It is better to stop work for the day, if no other use for the force can be provided.

A certain period of rest is as essential as the drainage itself.

The contractor alluded to claimed justly that his morning hours were the most profitable.

A lump of this quicksand, apparently dry, may very often be made "quick" by a little agitation alone.

Hard and apparently dry lumps will often become wet and pasty on their way to the dumping ground, so much so as to require additional labor to remove them from the carts.

The benefits of drainage, therefore, do not end until the material is *finally* disposed of.

It is useless to attempt excavation and hauling in wet weather, and a little time even is required after a storm, for the drains to reduce it to proper working conditions.

A close observance of the color is a very good guide as to the times for excavating it to the best advantage.

When at its best for easy and continuous shoveling, both in the case in point, and as observed elsewhere, its color was of a very light grayish tint.

When becoming disturbed by the agitation of continued travel and working it gradually deepened in color—and this became so well understood, that an ordinary workman was aware when it was prudent to change to another locality, and leave it to its required rest.

In its natural state in place, and before being disturbed by the workmen or drainage operations, the quicksand at a few inches below its

surface was compact, and offered considerable resistance to the penetration of spades or other working tools, and had a putty-like consistence.

It was free from sand or grit, and constituted the true engineers' quicksand, so-called or mis-called, where no sand enters into its composition.

The first discouraging weeks at the ditch-work were much improved upon by the remarkable increase in skill, and faithfulness, and efficiency of the men selected for this important part of the plan.*

The strong flow of water through the main ditch, with its collections from the minor ones, and through the ditches from each end of the cutting, indicated the success of the drainage operations.

The cost of excavating the quicksand at this place (exclusive of the expense of hauling beyond a moderate distance), under the circumstances related, was about nineteen cents per cubic yard, but to this must be added three and one-half cents for the cost of the great drain or cutting mentioned, and about four and one-half cents for the labor of constructing and keeping the sub-ditches and small drains throughout the cutting in good and effective condition.

This may be compared with the price at which an energetic contractor, by the common method, could *not* do the work at forty cents per cubic yard.

The saving in cost to the State was about eight thousand dollars, by the adoption of the plan which has been detailed in this paper, besides a saving of one-half in the time required to execute the work.

Portions of the quicksand excavation were so successfully treated, that at the present rates of labor they would not have cost above fourteen cents per cubic yard. And it should be stated that if the operations here detailed had been in use from the first, so as to include the whole

* One of the most discouraging and troublesome features, in the method detailed, is the apathy and indifference of the ordinary workman employed in keeping the ditches open and in good effective condition for drainage. The ditching is disagreeable, dirty and uncomfortable work, and there is a constant disposition to shirk it. The ditches are constantly filling up, sloughing in from the sides and swelling up from the bottom, and the water keeps the material in a sticky, pasty condition, exceedingly troublesome to handle or to remove from the shovel. The foreman often sympathizes and listens to the complaints of the men, and the usual "practical man" argument comes to the front. The immediate consequences of neglecting the minor ditches has little apparent force with the "practical" man. Moral suasion, deepening occasionally into some severity, and much personal supervision will probably always be necessary to success. In the case in point I was probably fortunate in the selection of the men for this work, and as stated, a few weeks showed a vast improvement in their efficiency; but it is well not to be discouraged when the very best efforts fail in accomplishing all that the manager is striving for.

body of the quicksand, the rate per cubic yard here given would have been considerably reduced.

The difference may be contrasted in time, cost and comfort, between excavating quicksand in its original condition when in place, by the ordinary methods in use for other materials, with that to which it is reduced by thorough drainage and careful management; or the difference between a man shoveling five or six cubic yards per day or about twenty in the same time.

This material which may have given so much trouble, first, to place it into the carts, next to haul it over its quaking surface, then to remove it from the carts, will, when finally disposed of on the embankment and exposed to the drying influences of complete drainage and sunshine, become so comminuted as to be carried off in clouds by the wind. In this state it is at the other extreme, and would be too dry for convenient shoveling.

In the opinion of the writer, hardly any case of quicksand excavation of any considerable amount could occur where it would not be profitable to first remove the water, even where natural drainage cannot be resorted to. The cost of pumping machinery of the power needed, worked either by hand, horse or steam, would soon pay for itself and work a magical change in the material. Even when the cost of machinery appears to add heavily to the expense of removal, yet the time saved, the comfort in doing the work, the saving in wear and tear, the greater ease in obtaining workmen, will be found profitable and far more satisfactory in all results.

On several of the works on which the writer was engaged, where the contractors paid but little attention to thorough drainage, the earth on each side settled to an extraordinary extent, laterally into the cuttings, for great distances on each side, occasioned by the slipping and flowing of substrata of quicksand in a semi-fluid state, weighted, as it was, by heavy superincumbent masses, so that several times the amount originally contained within the prism-lines had to be excavated and removed.

On one of our trunk lines of railway the grade was raised three times before the track could be laid, and the settlement of the surface on each side had then produced considerable damage to adjacent property.

It is well known, that when most of the water is removed from quicksand, it will bear quite a steep slope, as compared to the same material surcharged with water.

In these remarks the endeavor is made to separate the costs, expenses and method of excavating quicksand from that of other materials.

No small difficulty was occasioned, in the execution of the work, by encountering layers and strata of cemented or indurated clay and gravel, which interfered greatly with the plans for removing the quicksand.

These strata were not of sufficient thickness to make blasting profitable, offering much opposition to drilling, the pebbles being hard and apt to turn so as to continually present new surfaces to the drill, and they could not be passed until pulverization was to some extent or even completely effected.

The continued blows of a pick were slow in their effect, and the same was true of the heaviest hammer that a strong man could wield, or crows that two men could lift. I think power drills and a light, easily portable piling machine could have been used with good effect, drilling a line of holes a little distance back from the edge to produce a favorable line of fracture and subjecting the portion so cut off to heavier blows than could be effected by hand, first removing a portion of the supporting material from undeneath this hard material.

The cost of removing the cemented clay and gravel ran sometimes as high as one dollar and eleven cents per cubic yard.

Some other local questions such as long haulage, etc., have been eliminated as only embarrassing the subject under consideration.

The price of labor at the time was one and a half dollars per day for laborers, and four dollars for two carts and a driver.

A quicksand case, bearing an affinity to the subject here treated of, was under grave consideration by the Canal Board, of the State of New York some years ago, and similar questions have arisen a number of times since. It is desirable that the practice and decision of engineers should be rendered uniform, and the most effective method seems to be to place it before the Society for its consideration and action.

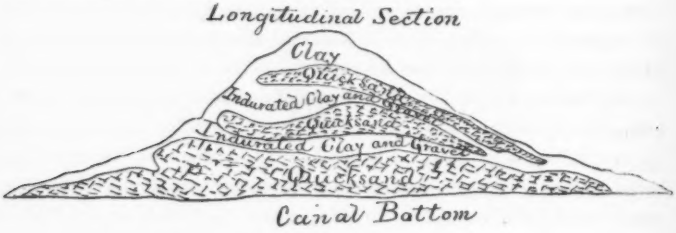
A heavy cutting on the State Works of New York, was composed of clay, sand, gravel, indurated clay and gravel, boulders and quicksand, the greater portion of which was of the latter material.

The excavations were made by teams and rail cars.

Ditches were used to a considerable extent; made and maintained at the contractors cost.

Some of the layers of quicksand, lying at greater elevations, were

more easily drained than the lower portions, and when this was effected its excavation and removal was comparatively easy.



The question in dispute was, whether it should, after drainage, be any longer considered as quicksand and paid for by the State as such, at a greater price than for common earth.

The length of the cutting was about one thousand yards, and the deepest cutting seventy-six feet.

The excavations were made from each end and at the centre.

The upper layer was well drained; the next below less so, but yet to a considerable extent; and the lower layer was much improved by ditching.

The upper layer was excavated at no greater cost than the adjacent clay; the second layer less thoroughly drained, retained its character of quicksand and cost more to excavate, and when placed in the cars it became a quivering and sticky mass before arriving at the dumping ground.

The contractors received no payment for draining the section, and all drainage by ditches or otherwise was at their own cost.

They had three classifications for earth excavation, namely, cemented clay and gravel, quicksand, "and all other excavation."

The question mentioned was so gravely entertained that it was considered necessary to obtain the opinions of several engineers, whose practice enabled them to express an opinion on the subject.

One stated that the real question was, "what was the material before a portion of it, namely, the water, was removed? If quicksand at the time of commencing the work, the payment of the quicksand price cannot be avoided."

Another said, "assuming the material to have been quicksand when the work was commenced, no methods adopted by the contractors at their

own cost, by which it was more easily excavated than was anticipated, can effect his claim to the price for quicksand. Such claim on his part is, therefore, consistent with justice as it is with usage."

Another thought that the contractor should not suffer for the results of his own sagacity, and that the cost of drainage should be considered in the same light as that for pumps or engines used for the same purpose.

Another engineer said, that much depended upon the explanations given by the engineers in charge at the time the contract was let, and upon the uniform practice on the work upon which the case occurred, and that the opinion of an engineer should be taken with much caution and due allowance for the circumstances. The result was that the contractor, after several years, settled with the state, no quicksand price being allowed on the upper strata nor upon a portion of the strata next below.

It would seem to the writer, as it may to others, that no grave question of this kind should arise in regard to the classification of this material, and that it should matter but little to the State, Company or others, who have contracted to have work done, in what manner it is performed (so that it is done in a workmanlike and reasonably speedy manner), and if those executing it choose to first separate its component parts and remove them separately at their own cost, the object being accomplished, there are no grounds for refusing payment.

Yet that there are now and have been such questions raised, one of the proofs is the case cited.

It has been said, that as the contractors worked the cutting from the two ends much of the water would, by its own gravity, separate itself from the upper layer of the material without trouble or expense to the contractors, and that he should not claim an advantage which was the result of natural laws.

The opposition made to the payment of the quicksand price, and the trial of the case by a responsible body like the Canal Board, accustomed to the consideration and trial of many cases relating to the execution of engineering works, as well as the diverse opinions of some of the profession, renders an engineer's decision a matter of grave importance not only to the contractor and the company, but to the engineer whose fiat so often decides the case, and has led to the foregoing statements and opinions, in the hope of eliciting such expressions of the views of the

members, as may be of valuable aid in the decision of future cases, and the avoidance of injustice or costly disputes between companies and their contractors.

Engineers will no doubt call to mind their own experience with conscientious members of Boards of Directors, whose minds become troubled when they see this formidable material reduced to the simplest conditions for excavation, and that their contractor is removing it with comparative ease, and that it is then very hard at times for the engineer to retain the directors' confidence, that his classification at an increased price is proper and right.

It need hardly be mentioned, that the expressed views of skilled engineers, such as it is hoped the discussions may bring out, would have great weight in the decision of these troublesome cases.

This paper has been entitled "Quicksand in Excavation," and it has been confined to the consideration of that branch of the general subject, namely, the proper management of this troublesome and uncertain material when it occurs in cuttings for railways, canals and other work not requiring the removal of much, if any, of it below the grade line.

But there are other descriptions of work where quicksand is encountered which may require much skill and care to safely provide for; as in the foundations of important and heavy structures; in pipe lines in cities; under massive buildings; under dams for retaining water, etc. Valuable data in regard to such cases are contained in the memoranda of most engineers, and if the interest felt in the subject by this Society is indicated, it would no doubt draw out much information covering wider ground than the writer has thought it best to occupy in a first paper on this subject.

The description of special cases, the nature of the difficulties and the methods of overcoming them, would be of great future use to the profession, more particularly as authors have greatly overlooked or omitted these important questions. Engineering text books give much information about other materials likely to occur in construction work; but this, one of the most troublesome and costly, has been strangely neglected.

Possibly it will be of service in this discussion to consider the origin of quicksands, and the peculiarity of their physical qualities upon which their characteristics depend. It may be assumed generally that the special mobility of such sands depends upon the presence of water fill-

ing the interstices of the mass. The mass yields to pressure in conformity to the laws of liquids or semi-fluids, varying with the degree of quickness. The degree of quickness depends upon, *first*, the gravity of the sand; *second*, upon the smoothness of the surface of the particular grains of sand; and *third*, upon the abundance of the water present with it.

Sand is a product of the action of wind or water on fragments of stone, by which, through the grinding away of the rough surfaces of the grains, they become smooth and polished. If transported under proper conditions, the grains are assorted and deposited according to size and weight, and so accumulate in large quantities, having grains with nearly uniform dimensions throughout the bed. Under some influences such beds may be percolated by currents of water saturated with lime or silica, which will be deposited on the grains of sand, roughening their surfaces, and when the process is long continued binding them into beds of sandstone. When water, free from such impurities, flows through the beds of sand they will continue as such, and when made from quartz, if the grains are very smooth surfaced, and water present, abundant enough to thoroughly fill the interstices, such sands will yield to pressure and be quicksands. In the absence of free water the friction of the grains of sand against each other will usually prevent the quickness. Obviously, the treatment will be to get rid of the water by ditching, sinking pipes and pumping it out, or cutting off its inflow.

The important question seems to be how to get water out of beds of quicksands, for when that is done, they will, in most cases, cease to be such, and will be tractable.

I venture to call attention to the possibility, in case of foundations, of injecting cement or cement-forming material into the bed of quicksand, or into seams of it when not easily controlled otherwise, converting it thus into sandstone by a quick method, very much as is done naturally by slow processes.

DISCUSSION.

WILLIAM R. HUTTON.—I have never had the fortune to meet in large quantities a material quite so bad as that described by Mr. McAlpine. There can be no doubt, however, that where drainage is practicable, it will enable the work to be executed in the shortest time and with least expense.

Of a somewhat similar material that has come under my notice, one or two cases will be cited. A railway track had been laid in light cutting upon a white clay full of water, although not *quaking*, and so soft that no amount of ballast would keep the track from sinking. Ditches five feet deep were dug on both sides of the road-bed, which drained it thoroughly and removed all the difficulty. In this case, as I remember, the water was carried in a seam of gravel under the clay, from which it had no outlet until reached by the drain.

At another place the cutting was deep and the material an absorbent white and yellow clay. The slopes, being drained by the excavation, maintained themselves tolerably well, although a number of small slips occurred. The road-bed, however, was very soft, and the track could not be maintained upon it. It was also very narrow, and the right of way insufficient to permit cutting back the slopes. Deep, open ditches were, therefore, impracticable, and, as an alternative, trenches were dug and filled with broken stone. This enabled the track to be laid, but the drains were liable to be choked by the earth washing down from the slopes. Tile drains would have been better.

But it is useless to cite cases of this character. Every engineer has met and overcome them, and the books are filled with them.

I have sometimes found great difficulty in making these slippery clays stand in embankments, when moved in winter or spring. After some months of dry, summer weather they seem to part with their water and become stable, as rain falling on their surface does not then penetrate deep enough to affect the mass. In one case, where a rock cutting was near, the sliding was checked by a heavy rip-rap along the lower part of the slope.

Mr. McAlpine will doubtless tell us at what slopes the cutting stood after being opened and drained; and it will be of interest to know the position of the embankment in which the material described by him was used, and the effect of water upon it after it had been thoroughly dried.

Pure clay is composed of silica, alumina and water, and the smaller the proportion of silica, the greater the quantity of water it will take up. This is the principal material forming the quicksands proper, and upon its greater or less admixture with granular matters—the sands of quartz and feldspar—depends its greater or less stability. The presence of mica, finely divided, appears to increase its tendency to move. When water in contact with it is confined by impermeable strata, it will hold large quantities. It is this material, which swells by absorption of moisture from the atmosphere, which has given so much trouble in tunnels, notably in some of the earlier English railway tunnels. Of this character also is the bad ground in the St. Gothard tunnel, where, however, according to the most recent reports, it does not swell upon contact with the atmosphere, having probably taken up all the water it can carry; but, remaining plastic or semi-fluid, exerts a pressure upon the supports "slow, constant and excessive," which is retained by arches not less than five feet thick, built of cut granite and laid in Portland cement. The clay met with in the Sutro tunnel, on the other hand, of which I have no precise description, swells very much and with a force that cannot be resisted, contracting, indeed almost closing, the tunnel, but which ceases to swell after the intruded material has been twice or thrice removed.

There are other materials, however, which bear the name of quicksands, and there is great diversity of opinion upon its character and the proper application of the term.

The river beds between the coast range of California and the sea are formed of sand which, during the dry season of summer, may be traversed anywhere, being perfectly firm, though loose and light. The water is small in quantity, and frequently stands in pools or disconnected ponds, the flow, such as there is, taking place through the sub-surface sands. But when the winter rains come, the rivers are in flood, and the sands, under the action of the current, become quicksands of the most formidable character, impassable except at the regular fords. These are *travellers'* quicksands, and I know too little of them to explain the change in their practical characteristics caused by the volume of discharge and the rapid current.

As failures are said to be more instructive than success, chiefly, I think, because they attract more attention to their details, the treatment of a case which, if not quicksand, was equally intractable, will be given.

In the construction of the Georgetown incline it became necessary to enclose a basin with an embankment and wall in the river, to be afterwards pumped out, shaped and lined. Over the rock bottom was 6 or 7 feet of silt, apparently a dark blue clay. It held water perfectly, and holes dug in it at low tide retained the sharpness of their edges after the tides and waves had passed over them. The contractor was therefore permitted, when making the preliminary dredging, to deposit some of the material upon the site of the embankment.

The bank was finished by dumping into the water clay and rock from the excavations, the clay dump being kept a short distance in advance of the rock, that the material might take its slope on both sides and the rock remain as a heavy rip-rap only on the outer slope.

After the completion of the embankment and wall, the basin was pumped out and the inside excavation commenced. At first it drained well and the work advanced, not without difficulties, but without unreasonable or unexpected trouble. But after a week's work, in an easterly rainstorm the bank settled, the high storm tide broke over the top, and the pit was flooded. The laborers, negroes, refused to work during the Christmas holidays, and everything was allowed to stand until after the New Year. When the bank was made up and the pumping resumed, it was found that a slide had taken place, which was caused by the compression and squeezing out of the dredged material in the bank. This became mingled with the more solid clay, and formed a semi-fluid mass, which would not stand at a less slope than about 1 to 5. It then became evident that the original plan of a sloped bank, kept in place by a heavy paving, could not be carried out; that a retaining wall, nearly vertical, must be built to such height as the slope at each point might require. A row of 3-inch sheeting was, therefore, driven behind a heavy stringer, which was thoroughly shored from the opposite side. As the excavation was carried on, other stringers were added below the first one, and well shored in like manner. But the instability of the material was such that, after excavating 3 or 4 feet on one side of the sheet-piling, the difference of pressure on the two sides caused a lateral movement of the lower portion of the mass, which bent the sheeting, pushing out its foot, and finally causing rotation about the lower stringer, and a further slip. A row of round piles was then driven, the better to support the sheeting, and with this the material, where not very deep, was excavated to the rock, and the slope wall or masonry built. But the

difficulty of getting in stringers and shores low enough to hold the bottom of the sheeting rendered it impracticable by this means to carry the work to the greater depths, in some places nearly 20 feet. Finally, a row of sheet-piling 12 inches in thickness was driven behind the rear line of the foundation, and shored, as before, against horizontal stringers. The foundations could then be excavated in short lengths, and the retaining walls built. The work was then completed without further difficulty, the retaining walls being carried up to meet a slope of 1 upon 2 from the top of the bank.

The question raised by Mr. McAlpine upon the classification is also of importance. Explanations given by the engineer at the letting should be in writing, and accessible to all bidders. It is a good custom at such times, when a question is asked which cannot be answered by a simple reference to specifications and plans or profiles, to write question and answer on a sheet to be attached to the profile, and retained until the settlement of the contract.

In the case referred to, an extract from the specification on the subject of quicksand would aid in forming an opinion. Supposing, however, that the contract contained a price for quicksand, but no specification concerning it, then if the material, when attacked by the contractor, was clearly quicksand, he would doutless be entitled to pay for it as such, whatever the condition to which his works, executed for the purpose, might reduce it. If before he reached it the material were drained by other works not carried out for the purpose, the question might be in doubt, and might depend upon the circumstances of the letting.

ERRATA.

Transactions, Volume X, page 238, July, 1881. Discussion by J. J. R. Croes, on Rain-Fall and the Flow of Streams. 5th line from top of page insert the figures 242, so that it will read (see p. 242).

Same number of Transactions, page 250, first line, for J. J. R. Cross, read J. J. R. Croes.

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TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

CCXXVII.

(Vol. X.—September, 1881.)

REPAIRS OF MASONRY.

By O. CHANUTE, Vice-President A. S. C. E.

READ AT THE 13TH ANNUAL CONVENTION OF THE SOCIETY, JUNE 15TH, 1881.

The important economical results accomplished on the Erie Railway (now the New York, Lake Erie and Western Railroad) within the last six years, by the use of béton, warrant making an exception to the general rule concerning methods which are protected by letters patent, and induce me to give an account of a material which is capable of extensive application by engineers.

Béton is simply a mortar of hydraulic cement and sand, mixed by means of patent machinery, with as little water as practicable, in pro-

portions experimentally ascertained by M. Coignet, a French engineer. When freshly made it looks like a loose, incoherent heap of damp sand, slightly coated with lime, and a more unpromising mortar can scarcely be imagined. When put into place, however, it forms a plastic mass, capable of being rammed into crevices of all masonry, of being moulded to all shapes, and made into monoliths of all kinds and sizes, from a statue or obelisk to a culvert or viaduct.

When set, it becomes a hard and imperishable stone, with a tensile strength of some 300 pounds to the square inch, and a crushing resistance of about 8 000 pounds per square inch, or about as strong as good granite, and when well made of good materials, neither time nor the elements seem to have any more effect upon it than upon the ancient Roman mortar which it resembles in its hardness and tenacity of adhesion to natural stones.

It is proposed to give an account in this paper of the uses to which bèton has been applied on the Erie Railway :

In May, 1875, the Portage viaduct, over the Genessee river, on the Erie Railway, was burned down. This viaduct, which is 850 feet long and 234 feet high above the bed of the stream, had been built of wood in 1852, and rested upon fifteen stone piers, from ten to thirty feet high. These piers were much injured externally by the fire, and when examined for the purpose of rebuilding upon them the iron viaduct which replaced the wooden one, they were found considerably shattered and shaken in consequence either of bad workmanship, the perishable nature of the stone, or the settling of the foundations.

In order to save expense, however, it was determined to use these old piers, provided they could be protected from the further disintegrating effects of the weather ; and investigation having pointed to the efficiency of béton for this purpose it was determined to try it.

A contract was accordingly made with Dr. Goodridge, President of the New York Stone Contracting Company—this being the name of the organization which controls the Béton process in this country—to repair these piers. This was done by encasing all portions exposed to the wash of water at the ordinary winter stage (which portions had been more or less shattered by frost and undermined by the action of water) with twenty-four inches of béton ; the ice breakers at the ends were also encased, and the tops of the piers were covered with a coat of béton two inches thick, to keep out infiltration, and the consequent splitting

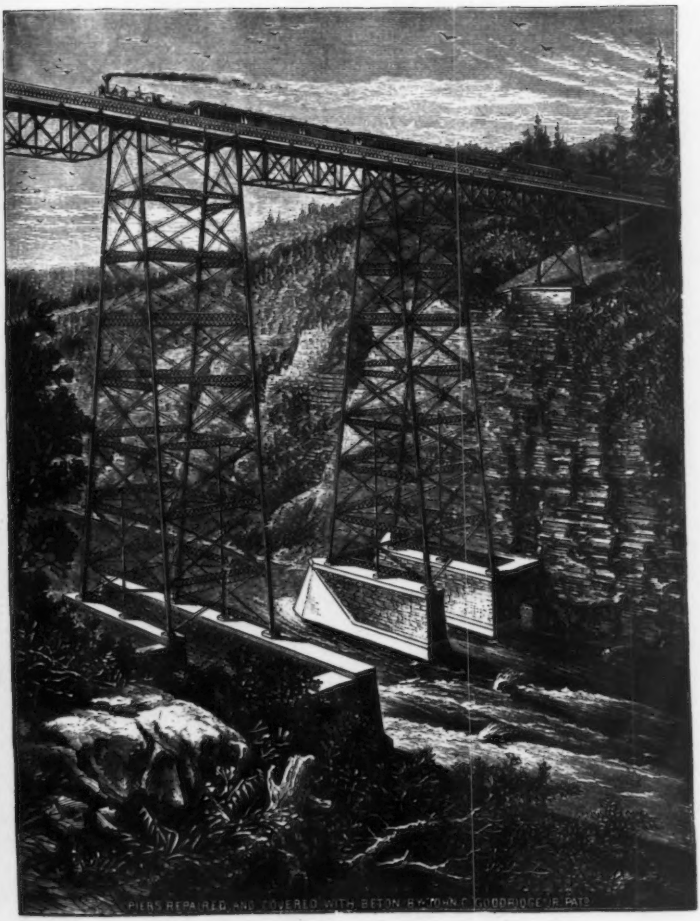

FIG. 1. PORTAGE BRIDGE.

apart of the masonry. The new pedestal blocks for the posts were also boxed in with béton to keep them firm and sound.

By examining the engraving of the bridge which is borrowed from the album of the "Stone Contracting Company" you can distinguish the portions of the piers covered with béton by their white, blank appearance. It is on top, on the shoulders of the ice breakers, and along the base, next to the water.

The amount paid to the Stone Contracting Company, for the béton work, came to about $6 000. It would have cost $40 000 to have rebuilt the piers for the new iron bridge, and thus the saving was very large. The result has been very satisfactory. The piers, to be sure, are not as good as new, but they have stood strains from the superstructure which would have shaken them all to pieces by this time if they had not been so protected.

From motives of economy less was done in 1875 than was advisable, and, as will be further stated in this paper, after an account has been given of some other uses béton has been put to, it will be employed this year in making further repairs at Portage.

The Warsaw Culvert.

Although the Erie Railway runs much of the way through a rocky country, few of the stones found along its line stand the weather. Many of the culverts, abutments and piers have therefore been eaten into by the elements, and in the course of years, not a few have been replaced by new structures.

When such culverts are under heavy embankments, their renewal involves the great expense and risk of digging them out, carrying the track upon temporary works, and rebuilding a new culvert and embankment under the trains.

In 1875 there was such a culvert near Warsaw, on the Buffalo Division, which threatened to fall into ruins. It was 146 feet long, fourteen feet in clear opening, and under an embankment sixty feet in height. The frosts had gnawed its bench walls and ring stones, until they had become an irregular mass of crumbling flakes, which came down with the slightest touch. Some of the stones were entirely gone, leaving cavities from three to six feet long, and extending back from one to three feet from the original face.

This culvert was more or less injured throughout its whole length, and hung together, apparently from the force of habit in those natural

arches, which form with time in thoroughly settled embankments. It would have cost about $36 000 to have digged it out and replaced it with a new structure, as had been done during the previous year with a similar culvert upon the Western Division; when the contractor for the Béton process offered to put a new face on the matter, for $2 200. In view of the results already accomplished at Portage, the offer was accepted.

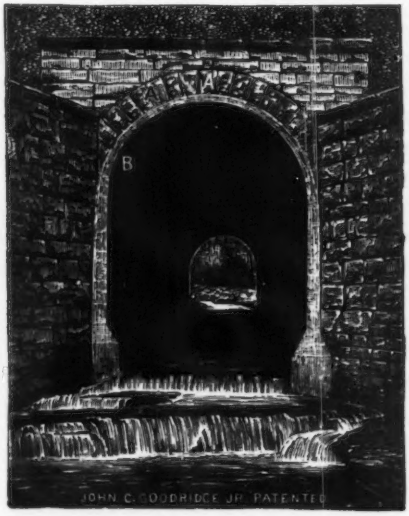

FIG. 2. WARSAW CULVERT.

The work was done in this way: Wooden centres were erected inside of the culvert, and on these were placed lagging plank, section by section, leaving a space of about four inches between the planks and the original face of the culvert. Into this space the béton, duly mixed outside, and wheeled into the culvert, was rammed by hand until every cavity and crevice (these were previously cleaned out) were duly filled. Some of these cavities extended clear back to the earth filling, all the stone having perished. The Béton lining was also extended down the bench walls to the rock foundation of the culvert. As fast as one section was filled, the centres and lagging were put up for the next, and the work proceeded as before, from the free end.

One week after the completion of the work the centres were struck; and when removed, together with the lagging, the inside of the culvert presented a hard, smooth surface, (except the saw marks and joints in the lagging plank which had been faithfully moulded by the Béton) and the work appeared to be entirely impervious to water.

A photograph of the end of this culvert will be found reproduced in Figure 2. *A* is the original arch, and *B* the Béton lining, which has thus far stood perfectly.

It was completed just before cold weather, and some misgivings were felt by the railroad officers as to the effect of the succeeding winter. It was feared that water might percolate through the embankment and joints of the old work down to the béton, and there freeze and injure it. The culvert was therefore closely examined the next spring, but not a weather mark nor any change whatever could be discovered.

It was thought, however, that perhaps the winter of 1875 had been too mild to test the material severely, and that another season would bring different results and show some defects or weak points in this method of saving money in the repairs of masonry. No further work of this kind was therefore done in 1876, and in the spring of 1877 a new examination was made of the Warsaw Culvert to detect any possible injury. None whatever was found, but it was then, and it is now, after a winter as severe as heart could wish, as perfect as when originally built.

The Clifton Culvert.

In the spring of 1877 it was reported that a culvert at Clifton, 12 miles from Jersey City, needed to be rebuilt. It had originally been constructed of red sandstone from quarries in the vicinity, and was not only dilapidated and peeled by the weather, but it had settled upon its foundation, so that it was in a very dislocated and disjointed condition. Its wing walls had parted from its main walls, the parapet had been pushed out by the thrust of the earth, so that it partly overhung the arch, and, singular to relate, it being under a shallow bank, the vibrations of the trains acting upon the earth that pressed against the culvert, had actually lengthened it, so that its barrel was two feet longer than originally built. We know this to be a fact, for we found the original record plan, we measured the culvert carefully, and found enough openings in the joints fully to make up the two feet it had lengthened.

It would have cost $6 000 to have rebuilt this culvert, but a contract was made to repair it for $600. This was done by lining it with an inside ring of béton, 4 inches thick, rammed into all the crevices and joints, and building béton buttresses at the ends, to prevent any further

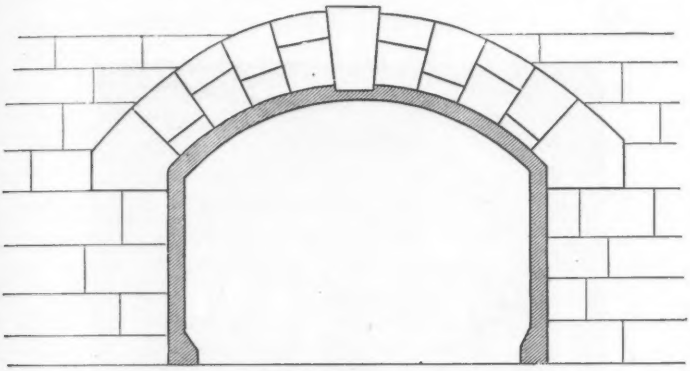

FIG. 3. CLIFTON CULVERT.

creeping away of the structure from under the trains. The success has been complete, and the culvert is now as good as new. A geometrical end view of it is given in Figure 3.

Bergen Tunnel.

In the fall of the same year it became necessary to make some repairs to the Bergen Tunnel at Jersey City. This tunnel is 4 316 feet long, and driven through trap rock. This, although very hard and unaffected by the weather, is full of seams and faults, and being entirely unstratified, it comes down in blocks of isolated stones, which set dangerous traps for the trains. Some portions had been arched from time to time, but this had been done with brick, and in the course of years, alternate freezing and thawing had peeled off the face from the bricks, generally in flakes about one inch thick, until in some places the arching had been eaten into for a depth of 8 inches.

It was decided to arch over an additional section 130 feet long, where the naked trap rock was badly shattered, and to reline with a thin coating of béton another section 30 feet long, in which the bricks had been most injured.

This was done by erecting iron centres, so arranged as to clear the trains, placing on the centres wooden lagging plank, and ramming the space between them and the face of the rock or brick, full of béton, the latter being mixed on cars in the tunnel.

This work was all done at night, in order to have the least annoyance from trains, of which some 200 pass through every 24 hours.

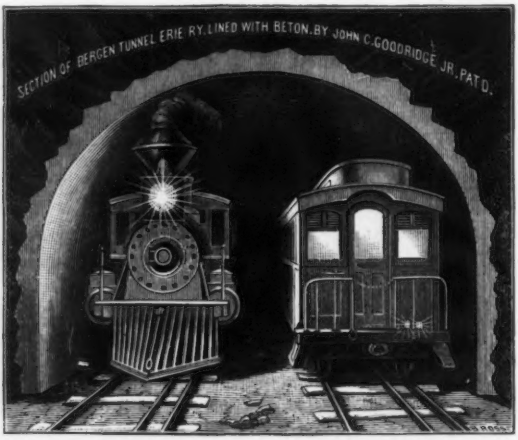

FIG. 4. BERGEN TUNNEL.

Figure 4 represents a section of that portion of the tunnel in which the béton was applied to the rock. When an infiltration of water was struck, in order to drain it and to prevent the formation of the stalactites of ice which hang down (and fall down) every winter from the rock, drain tubes were left in the beton by inserting hollow blocks made at the factory.

The work was successfully accomplished, and has stood perfectly ever since.

Buffalo Division Culverts.

Thoroughly convinced by these successes, a further contract was made in 1878 to repair, by the same means, a number of culverts on the Buffalo Division, which were getting into the same condition as the one at Warsaw, which I have described.

The following is a list of them :

No. of Culvert.	Length in Feet.	Span in Feet.	Crown of Arch to Foundation. Feet.	Height of Embankment. Base of Rail to bed of Stream. Feet.
80	147	10	17	87
3	141	10	12½	62
112	118	6	7	72
100	100½	6	9	39
4	112	10	13	63
77	52	6	10	28
101	46½	5	8	24
104	52	5	8	24
105	46	5	8	24
49	65	6	9	33
51	87	5	8	32
54	71	6	9	34
73	117	6	8	48

These 13 culverts, which had been built in 1851–2, had been nursed for some years, and exhibited all the ills to which masonry is subject in its old age. The stones were disintegrated, portions had caved in, the foundations were undermined, the bench walls were broken-backed, the arches were distorted, and the ends and parapet walls were thrust out. These were repaired with appropriate doses of béton.

Figures 5 and 6 show the end of culvert No. 101, and Figures 7 and 8 the end of culvert No. 4, before and after taking Dr. Goodridge's "Béton Specific."

I regret that I cannot show you also photographs of the interior of these culverts, to exhibit their other defects. These were much worse than those shown.

FIG. 5. CULVERT 101. BROKEN.

FIG. 6. CULVERT 101. REPAIRED.

FIG. 7. CULVERT 4. BROKEN.

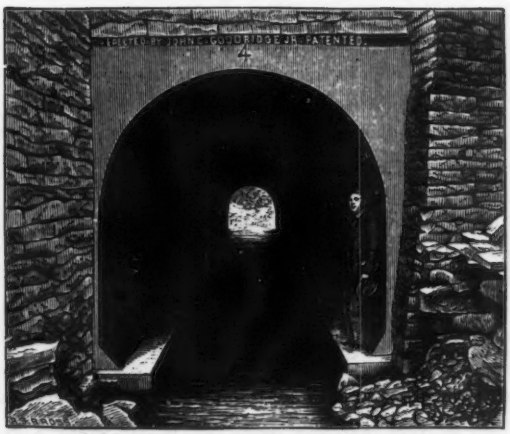

FIG. 8. CULVERT 4. REPAIRED.

FIG. 9. CULVERT 80. REPAIRED.

Figure 9 shows how Béton buttresses were applied to culvert No. 80, which is built on a slant on a sloping bed of shale, which disintegrates with the weather. An invert, partly shown in the cut, was put in to prevent further injury.

Figure 10 shows a similar invert in culvert No. 112. The middle of this had caved in, and the arch was distorted. This culvert was 118 feet long.

Figure 11 shows the new form given to culvert 105, in which the ends were down, and the interior much injured.

In all cases in repairing these culverts, all the loose mortar was picked out of the joints, the loose flakes of stone were knocked off, and the béton was rammed into all the holes and interstices.

We estimate that it would have cost to dig out and trestle these culverts, some of them being, as will be seen by the table, under embankments from 60 to 80 feet deep, and to have rebuilt them with new masonry, at say $10 a yard, the sum of about $80 000. We paid the contractor for repairing them $15 112 45, and we estimate that the labor of our carpenters, making and erecting centres, the free transportation of men and materials over the road, &c., &c., may have amounted to $5 000 more, so that the aggregate cost to the railroad was about $20 000.

The economy of the process was, therefore, marked and monotonous. All the culverts have stood perfectly ever since.

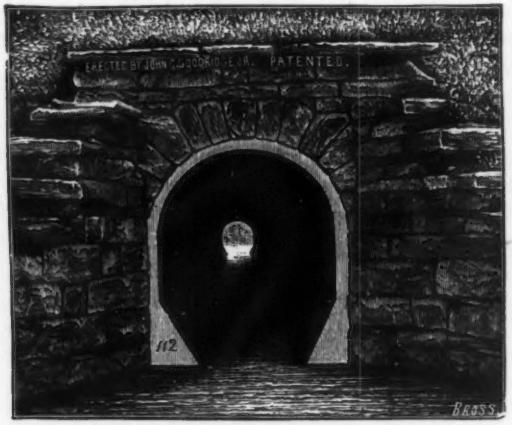

FIG. 10. CULVERT 112. REPAIRED.

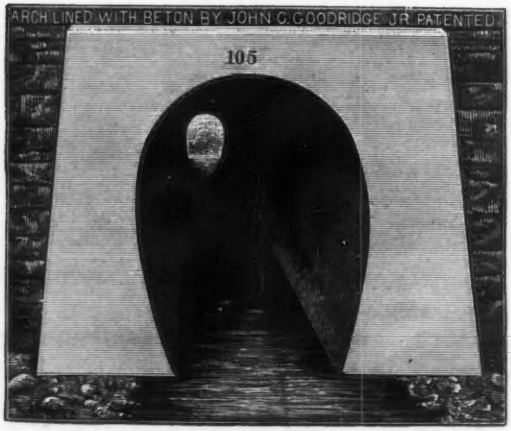

FIG. 11. CULVERT 105. REPAIRED.

West Paterson Bridge.

In the spring of 1880, the two piers, under the double-track iron bridge over the Passaic river, at West Paterson, were reported as cracking open and falling asunder. They were founded upon cribs, resting on the sandy bottom of the river, and the settling of the cribs, together with the jarring of the trains, was shaking the piers to pieces. It would have cost $12 000, and have involved some risk, to have rebuilt them under the bridge. After careful consideration and discussion, it was decided to envelope them entirely in a shell of béton from 4 to 12 inches thick. For this purpose wooden frames, planked inside, were erected at a suitable distance off, all around the pier, and the space between the planks and the stones was rammed full of béton. A coat 4 inches thick was also put on top, the whole enclosing six iron rods, three on a side, which had been temporarily put around the pier, to keep it from tumbling apart while its permanent repair was under discussion.

FIG. 12 WEST PATERSON BRIDGE.

The cost has been $6 000, and it is confidently believed that the piers are now good for many years; for the béton being an average of 12 inches thick on the sides, and 4 inches on top, and of a tensile strength of say 300 pounds per square inch, it would require an internal stress in the pier of

One side,	12 ft.	× 12 in.	× 12 in.	× 300 =	518 400 pounds.
Other side,	12 ft.	× 12 in.	× 12 in.	× 300 =	518 400 "
Top.....	5 ft.	× 12 in.	× 4 in.	× 300 =	72 000 "
					1 108 800 "

to burst its shell asunder, while the 6 iron bolts 1⅛ inches diameter, are only good for 300,000 pounds.

These piers are shown in Figure 12.

Dam at Portage.

In the fall of the same year in became necessary to make further repairs at Portage. The stones in one of the piers which had been injured by the fire were found to be flaking off dangerously near to one of the pedestal blocks, which carry the posts. This was easily repaired and further disintegration prevented by a buttress of béton over the injured spot.

Another pier was found more seriously affected. It had been built on top of a loose mass of rubble stone about 20 feet thick, thrown out when the Genessee canal was excavated, and, although strong enough to carry the wooden trestle, with its many posts, proved insufficient to carry the concentrated weight on the two iron posts which constitute the iron piers. Their weight had broken the back of the stone pier and forced down the outer ends some two inches into the rubble beneath. There was no telling where the injury would stop, and repairs were urgent. As it was late in the season when this was discovered, temporary repairs only were attempted. These were made by throwing out béton buttresses, beyond the ends of the pier, thoroughly bonded with it, and thus increasing the bearing area upon the loose rubble to about double the amount it had before. This has stopped further settling for the present, but to be entirely safe, we deem it necessary to extend the foundations under the iron posts either down into or entirely through the loose rubble, which is on a sloping bank of rock.

This we propose to do by drifting in narrow galleries through the loose rubble under the pier, and filling them with béton, which, when thoroughly set into stone, we propose to use as the sides and roof of other galleries, to be likewise drifted in and filled with béton, until we have a solid mass under the pier to a suitable depth.

I will tell you next year how we have succeeded.

We also propose to administer béton to the Genessee river. This has worn its way to a depth, varying from 200 to 600 feet, through the Portage group of clay shales, which have a bad notoriety for their disintegration under the action of the weather.

When the Portage bridge was first built, a waterfall 60 feet high had its crest 240 feet down stream from the bridge. It wore back, first in the shape of a horseshoe, and then all on one side, so that now, the nearest point in the top of the cascade is only 119 feet from one of the piers, and it is wearing back at the rate of about 15 feet a year. The chief trouble arises from the shaly, rocky bed of the river, which cleaves into blocks, shells off and is swept down the waterfall by the floods. Operations were begun last fall by running a béton dam 210 feet long and 3 feet high, which deflects all the water, at ordinary stages, from the portion where the rock has been wearing away fastest, but is submerged in floods; and will be followed up this year by filling in with rubble masonry a cavity in the rock, where the water is boring a dangerous channel nearest to the pier, and putting an apron or floor of béton over the whole bed of the stream where there is fear of its wearing back.

Blauveltville Culvert.

The preliminary work at Portage last fall occupied so long, that winter was upon us before we could repair a culvert of 16 feet span at

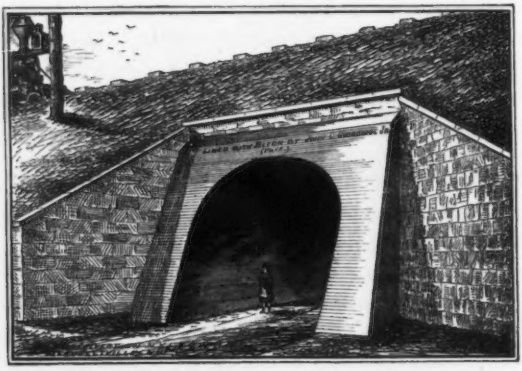

FIG. 13. BLAUVELTVILLE ARCH.

Blauveltville on the Piermont Branch, which carries a wagon-road under our track. However, in December the travel was turned over to an adjoining road, both ends of the culvert were boarded up, a couple of stoves were put in it, the pipes run out through the ends, and the béton men, provisioned with the necessary sand and cement, as food for their machine, went into winter quarters. They emerged this spring, leaving a new culvert lining behind them.

The end is shown on Figure 13.

Cost of the Work.

In doing this work, different prices have been paid, according to the difficulties of the various locations; varying from 60 cents to $1.00 per cubic foot, or from $16.20 to $27.00 per cubic yard. No new structures have been built entirely of béton, because, although they could be made considerably lighter in consequence of the greater strength of the mass, thus forming one single monolith, we have not deemed such structures more economical than masonry, where good stone can be procured at about $10.00 a cubic yard in the work. Where, however, stone is scarce and sand plenty, the béton would be the cheapest.

The cost would be reduced, if it were found possible successfully to use some of our American cements. A Portland cement, made at Boulogne, in France, has been used exclusively on the works above described, and the contractor says that his attempts to make good béton with American cements have resulted in failures. There have been failures also in France; some of the sewers of Paris, lined with some cheap stuff, are said to have peeled off, and the viaduct of La Vanne, which was wholly built of béton, is said to have cracked and flaked off to a dangerous extent. The proportions used for this structure, I understand to have been

20 parts of sand,
4 " lime,
1 " cement.

So that this is a formula clearly not to be used. In fact, I can give you no formula, as the proportions are said to vary with the fineness of the sand, and the character of the béton which is required.

We have preferred to have all our work done by contract instead of attempting it ourselves, in order to make sure that the proportions and workmanship should be controlled by experts. The results have been

entirely satisfactory. Large sums of money have been saved, not a single failure has occurred, and the repaired works seem likely to endure as long as if originally built of sound stones.

It is believed that the methods which have been described, are capable of still further adaptation and extension. Existing structures, the rebuilding of which would seriously interfere with the continued use of a road, canal or edifice, can be repaired with béton, as has been shown, without interference with the traffic, and at a cost of from ten to twenty per cent. of the expense of a new work. This can also be done very rapidly, six thousand cubic feet of béton, or over two hundred cubic yards, having, in some instances, been put in in a single day, so that engineers who may adopt this method of repairing masonry may be certain of saving both time and money.